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Mobilization of Scientific Resources—IV, The U. S. Navy

THE August, 1943 issue of this Journal featured the mobilization of civilian research agencies for the war. Continuing the discussion of the place of research in the war effort, there is presented in this issue a series of papers on research in the Navy. Naturally, much of the actual research is secret and cannot be published at this time. However, the broad organization of research in the Navy can be described and is illustrated in many cases with examples which are being made public in this issue for the first time.

The papers presented make amply clear the invaluable role which research plays as a factor in modern sea power. Few will question the fact that investments in military research have paid extraordinarily high dividends. Last June, at the time of the twentieth anniversary of the Naval Research Laboratory, President Franklin D. Roosevelt paid tribute to the contributions of the scientists to the war effort in the following words: "I take this occasion as your Commander in Chief to express my deep appreciation of the achievements of our scientists, both in the government and in commercial laboratories, who have bent their efforts to perfect our instruments of war and give us superiority over our enemies. I speak for our men in arms, whose fighting spirit reflects confidence in the excellence of their equipment. I speak also for the people of the nation who love peace. We all look forward to the days of peace when our scientists can once again turn their talents to improving the scale of living for all mankind."

This issue could not have been prepared without the complete cooperation of many high ranking naval officers. The Editor wishes particularly to express to Rear Admiral J. A. Furer, U.S.N., Coordinator of Research and Development, deep appreciation for his guidance and generous assistance in formulating the general plan of the issue. Acknowledgment is also made to the chiefs of the various bureaus of the Navy for their enthusiastic support. The photographs used in this issue are nearly all official U. S. Navy photographs which have been supplied by the authors and by the Office of Public Relations, Navy Department.

For April

Special issue on the Physics of Rubber and Other High Polymers. Papers on the following topics will be included in this issue:

Theory of the Elasticity of Rubber
GR-S, An Elastically Inverted Polymer
Materials under Dynamic Shear Stresses
Drift and Relaxation of Rubber
Light Scattering in Solutions
Elasto-Viscous and Stress-Optical Properties
Rheological Properties of Rubber
A New Extrusion Plastometer
X-Ray Studies of Chain Polymers
X-Ray Structure of Rubber
Stress Relaxation of Rubber Stocks
Hysteresis Losses in High Polymers
Thermal Expansion in High Polymers

Official U. S. Navy Photograph

THE HONORABLE FRANK KNOX, *The Secretary of the Navy*

The Secretary of the Navy is head of the Navy Department and all naval boards and offices are generally administered by him. Under his general direction, duly appointed officers are responsible for all combat and logistic operations and for all operating services of the Navy. The Secretary of the Navy has general supervision of the design, construction, equipment, maintenance, and manning of the fleets and shore stations of the Navy; and he performs such other duties as the President, who is Commander in Chief, may from time to time direct.

Organization of the United States Navy*

THE United States Navy is even in peacetime a vast and complex organization; during wartime, the great and rapid expansion which has taken place makes its organization even more complex. In an attempt to place in better perspective the research activities which are carried on by special agencies within the Navy Department, a brief outline of the present organization of the Navy will be attempted. While many features of the organization have a somewhat permanent character, many changes are likely to occur, particularly in personnel, as the war progresses.

Under the Constitution, the President is specifically designated as the Commander in Chief of the Army and Navy of the United States. The Navy Department and the Office of the Secretary were established by an act of Congress approved April 30, 1798. The Department is charged, under the general direction of its Secretary, with the supervision and maintenance of a naval establishment in readiness for the performance of such duties as the President may order. The principal advisers to the Secretary are the Under-Secretary, the Assistant Secretary, the Assistant Secretary for Air, the Commander in Chief United States Fleet and Chief of Naval Operations, the Chiefs of the seven bureaus, the Judge Advocate General, the Chairman of the General Board, the Director of Shore Establishments, the Budget Officer, the Commandant of the United States Marine Corps, and the Commandant of the United States Coast Guard.

In his 1942 annual report, Secretary Knox has emphasized that the Navy Department and the Navy Establishment are separate and distinct entities. Operations, both military and industrial, are conducted by the Naval Establishment; it is the function of the Navy Department to supervise and maintain the Naval Establishment so that it may conduct the necessary operations. The work of the Navy Department is thus in the field of administration, procurement, finance, and auxiliary services. Secretary Knox points out that this distinction should be borne in mind in reading reports of the activities of the bureaus and offices of the Navy Department.

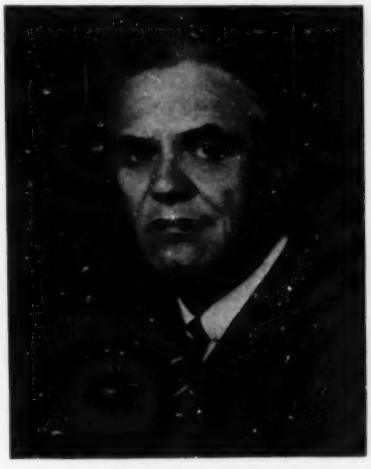
NAVY DEPARTMENT

Directly under the Secretary of the Navy are several important bureaus and offices, among which are the General Board, which is charged with the duty of studying carefully all matters of

* This article, while based upon the latest available Annual Report of the Secretary of the Navy and upon other Navy publications, has been written by the Editorial Staff of the Journal, and hence does not constitute an official Navy statement of organization. The material presented has, however, been cleared for security by the Office of Public Relations, U. S. Navy Department.

Official U. S. Navy Photograph

JAMES V. FORRESTAL, *Under Secretary of the Navy*



Official U. S. Navy Photograph

RALPH A. BARD, *Assistant Secretary of the Navy*

Official U. S. Navy Photograph

ARTEMUS L. GATES, *Assistant Secretary for Air*

Navy policy and of making recommendations to the Secretary; the Office of Budget and Reports; the Office of Procurement and Material; the Office of the Judge Advocate General; the Shore Establishments Division, which is concerned with the departmental administration of Navy Yards and Naval Stations; the Office of the Coordinator of Research and Development; etc. The last-named office was set up in the Office of the Secretary for the purpose of unifying the Navy's research activities. The duties of the Coordinator are to provide the Secretary and the bureaus and offices of the Navy with full information on research and development work both within the Navy and by outside agencies, and to cooperate with other agencies in the formulation of coordinated programs of research.

The Office of the Commander in Chief, U. S. Fleet and Chief of Naval Operations was set up when the duties of these two officers were combined early in 1942. These duties now devolve upon an admiral who is the principal naval adviser to the President on the conduct of the war and the principal naval adviser and executive to the Secretary of the Navy on the conduct of the activities of the Naval Establishment.

As Commander in Chief, United States Fleet, this admiral has supreme command of the operating forces and is directly responsible for these forces to the President under the general direction of the Secretary. He is assisted by a staff composed of the Chief of Staff of the U. S. Fleet, Deputy Chief of Staff, five Assistant Chiefs of Staff, and other necessary officers. This headquarters' staff is organized into five divisions: (1) the Plans Division, (2) the Combat Intelligence Division, (3) the Operational Division, (4) the Readiness Division, and (5) the Anti-Submarine Division.

As Chief of Naval Operations, this admiral is charged under the direction of the Secretary with the preparation, readiness, and logistic support of the operating forces and with the coordination and direction of effort to this end of the bureaus and of other offices of the Navy Department. His duties in this office are contributory to his paramount duties as Commander in Chief. Assisting the Chief of Naval Operations are the Vice Chief of Naval Operations, the Sub Chief of Naval Operations, the Deputy Chief of Naval Operations (Air), the Assistant Chief of Naval Operations for Materiel, and other necessary officers.

The Office of the Chief of Naval Operations is organized into the following divisions: (1) Logistic Plans Division, concerned with plans for implementing current and future operations; (2) Central Division, which has cognizance over general regulations and orders, international relations, and administers places under naval occupation and is responsible for many other matters not clearly assigned to other offices; (3) Naval Intelligence Division, which is responsible for the collection and classification of information for the Department; (4) Pan-American Division, concerned with planning and preparation of policies affect-

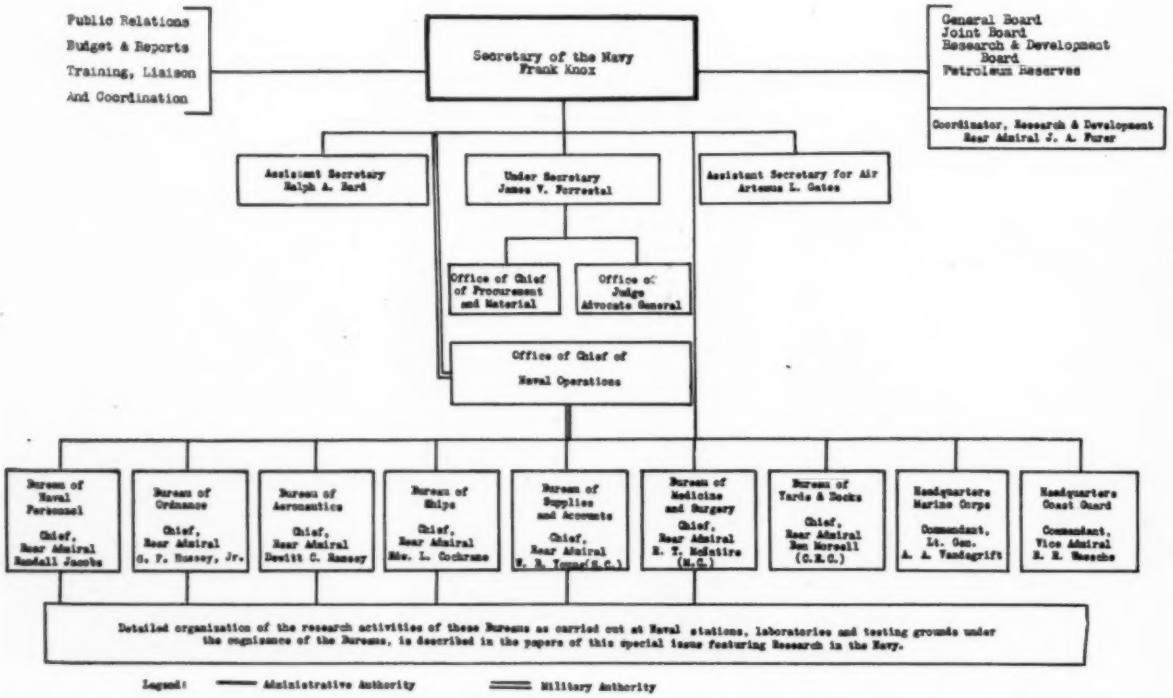


Chart showing organization of the Navy Department with particular emphasis on research activities. Officers are listed as of February 1, 1944.

ing American republics; (5) Naval Communications Division; (6) Inspection Division, concerned particularly with inspections and trials of newly constructed naval vessels; (7) Fleet Maintenance Division; (8) Hydrographic Office; (9) Naval Observatory; (10) Base Maintenance Division; (11) Aviation Planning Division, concerned with short and long range plans for numbers and types of planes, personnel requirements, and auxiliary facilities; (12) Aviation Personnel Division, concerned with procurement, assignment, and personnel policies, (13) Aviation Training Division; (14) Flight Division, which handles safety rules, legal matters, etc.; (15) Air Information Division; (16) Naval Air Transport Service Division; (17) Marine Corps Aviation Division; and (18) Naval Transportation Service Division.

Most of the technical and scientific research in the Navy is carried out by the bureaus and laboratories under their cognizance. A brief description of the various bureaus follows.

The Bureau of Naval Personnel is responsible for the procuring, training, and assigning to duty the officers and enlisted men who man the ships of the United States Fleet.

The Bureau of Ordnance is charged with the design, manufacture, procurement, maintenance, issue, and efficiency of all offensive and defensive arms and armament, as, for example, armor, guns, torpedoes, mines, depth charges, bombs, ammunition, war chemicals, and devices for the control of guns, torpedoes, and bombs.

The Bureau of Aeronautics is concerned with the design, construction, fitting out, testing, repair, and alteration of Naval and Marine Corps aircraft. The enormous increase in interest in aircraft during the past two years has led to much experimentation and development. Much of this work has been carried on by the National Advisory Committee on Aeronautics, but experimental projects have also been emphasized in the Bureau of Aeronautics itself.

Official U. S. Navy Photograph

ADMIRAL ERNEST J. KING
Commander in Chief, U. S. Fleet and Chief of Naval Operations

The Bureau of Ships is concerned with the general design, structural strength, stability, and seaworthiness of all ships of the Navy except airships. It has cognizance of most of the electrical equipment on board ship except that used for fire control. This includes the design, manufacture, installation, and maintenance of all radio and sound equipment both for shore and for ship use. The Bureau prepares specifications and prescribes tests for all material, equipment, and machinery under its cognizance. To carry out much of its work the Bureau of Ships nominates to the Bureau of Personnel specially qualified officers for engineering duty at sea and on shore, including those for duty as supervisors of ship-building, inspectors of machinery, and inspectors of Navy material. The Bureau recognizes that the effectiveness of our fighting forces depends to a large degree on the effectiveness of research development and tests, and of our ability to incorporate this knowledge in actual weapons, and has, therefore, sponsored a considerable amount of research by the Bureau itself and by the laboratories under its administrative control.

The Bureau of Supplies and Accounts is concerned with the procurement, purchase, warehousing, and shipment of our supplies, fuel, and other materials for the Navy, except for the procurement of special technical items and the storage and issue of medical stores, ammunitions, projectiles, mines, and explosives.

The Bureau of Medicine and Surgery is charged with, and responsible for, the maintenance of the health of the Navy, for the care of the sick and injured, for the custody and preservation of related records, accounts, and properties, and for the professional education and training of officers, nurses, and enlisted personnel of the medical department. Research activities in the field of medicine have been greatly stressed in the past few years. Through cooperation with the National Research Council, the Office of Scientific Research and Development, and with other government laboratories this program has been expanded to keep pace with the rapid advances in the field of medicine as a whole.

The Bureau of Yards and Docks has been set up to assist all bureaus and offices of the Navy Department in developing, planning, and administering the design, construction, and major repairs of the naval public works and public utilities, such as drydocks, marine railways, harbor structures, power plants, railroads, heating, lighting, telephone, water, and sewer services, and all types of buildings. Because of the far-flung network of bases which enables the fleet to operate in every ocean of the world, the activities of this Bureau have been greatly accelerated in the past two years.

THE NAVAL ESTABLISHMENT

The Naval Establishment comprises the United States Fleet, the United States Marine Corps, the United States Coast Guard (when assigned to the Navy), the Naval Districts, Special Naval Defense Areas, the Naval Shore Stations, Advance Bases, and all other components, commands, and stations of the United States Navy whether at home or abroad.

The organization of the U. S. Fleet varies from time to time depending upon type of offensive

Official U. S. Navy Photograph

ADMIRAL ROYAL E. INGERSOLL
Commander in Chief
Atlantic Fleet

Official U. S. Navy Photograph

ADMIRAL CHESTER W. NIMITZ
Commander in Chief
Pacific Fleet

Official U. S. Navy Photograph

ADMIRAL WILLIAM F. HALSEY, JR.
Commander, South Pacific Area
and Force

or defensive action required. Shortly after the attack on Pearl Harbor, the Fleet was drastically reorganized to meet the new conditions that had been thrust upon it. The first major step toward streamlining and unifying the central naval command was the Executive Order which provided that the Commander in Chief, U. S. Fleet take command of the operating forces of all of the fleets of the Navy and the Naval Coastal Frontier Commands. Because of the damage caused by enemy submarines to Atlantic coastwise shipping, Sea Frontier Forces were established and placed under the Commander in Chief, U. S. Fleet. The Amphibious Force was reorganized to consist of three groups: (a) transports and amphibious vessels; (b) an amphibious corps; and (c) supporting units.

Organization of the Pacific Fleet was completely revised. In place of the traditional Battle Force and Scouting Force commands, which were abolished, there were set up new, closely knit fleet type commands in the following groups:

Battleships	Service Force
Carriers	Amphibious Force
Cruisers	Submarine Force
Destroyers	Patrol Wings.

The effect of this reorganization was to establish the same type commands in each fleet.

Finally, there was a complete reallocation of command of the naval forces of the United States, as follows:

(a) Directly under the Commander in Chief, United States Fleet, and the Chief of Naval Operations was brought:

(1) United States Atlantic Fleet
(2) United States Pacific Fleet
(3) Sea Frontier Forces
(4) Special Task Forces.

(b) Under the Vice Chief of Naval Operations:

(1) Naval Local Defense Forces
(2) Naval Transportation Service
(3) Special Duty Ships
(4) Naval District Craft.

In addition, the South Pacific Force was established, and ordered to operate directly under the Commander in Chief, United States Pacific Fleet.

RESEARCH IN THE NAVY

In the following pages the research activities of the Navy are described. The first article by the Coordinator of Research and Development covers the Navy as a whole. There then follow descriptions of the researches in the Bureau of Ships, Bureau of Ordnance, Bureau of Aeronautics, Bureau of Supplies and Accounts, Bureau of Medicine and Surgery, and the Bureau of Naval Personnel. In those cases in which several laboratories operate under a single bureau, the individual papers describing the laboratories are preceded by general papers describing the organization and coordination of research in the particular bureau concerned.

Research in the Navy*

BY REAR ADMIRAL J. A. FURER, U.S.N.
Coordinator of Research and Development

DURING the past twenty-five years the most striking thing in the development of the art of making war, if so despicable an activity as making war can be called an art, is the part that science has played in aiding the fighting man with his problems. No great changes have taken place during that time in the fundamental weapons themselves. The fighting is still being done as in the past, with missiles, explosive bombs, and cold steel. Science has, however, very greatly influenced the making of war in lessening the limitations that distance places on man's normal perceptions of sight and hearing, in increasing the accuracy of gun fire and of bombing, and in increasing the speed and precision with which fighting forces can be moved from place to place whether by land, by sea, or by air. In addition science has, of course, made many contributions to the improvement of weapons and devices of warfare.

Until the end of World War I new weapons, countermeasures to the enemy's weapons, and improvements in war material in general came into being largely through the efforts of individual inventors or through the research and engineering activities of the government establishments that specialized in such work. Often in the past an invention that was not intended primarily for making war, ultimately found its chief application in that field. It is unlikely, for example, that gun powder, when it was invented in China, was intended as a propellant for missiles. It is in fact likely that gun powder was known for many years before it was used at all as a propellant for weapons. On the other hand, the invention of the explosive shell by General Paixhans in 1819 had for its object no other purpose than to increase the destructiveness of projectiles fired from cannon.

REAR ADMIRAL J. A. FURER

Two outstanding inventions which have had a profound influence on sea warfare, but which were not intended for that purpose, are the electric storage battery and the internal combustion engine. Records of attempts at submarine navigation go back to the days of Henry VIII. During the latter part of the eighteenth century and all through the nineteenth century literally hundreds of experimental submarines were built by inventors in every country of importance in the world. It was not, however, until the electric storage battery and a reliable internal combustion engine appeared in the last decade of the nineteenth century that a successful submarine was also produced. The submarine then became an efficient instrument of war and has ever since remained an important part of the armaments of even the smallest nations.

World War I led to new conclusions on a great many subjects. One of these was that wars are no longer the business of only armies and navies but that the civilian population must in a large measure be mobilized to fight a war successfully. The need for mobilizing and organizing science for war was seen to be particularly important, as now every field of knowledge contributes to the war effort. The ramifications of modern science are so great that no one person can comprehend more than a small sector of the whole. This fact underlined the necessity for coordinating for war the work of the scientists if the maximum benefit was to be derived from their efforts. In order to get a picture of what is involved in such coordination a brief statement of the part which the government plays in scientific research in times of peace will be of interest.

* The opinions contained herein are those of the author alone and do not necessarily reflect the official opinion of the Navy Department or the naval service at large.

The scientific activities of the federal government in peacetime are normally spread through about forty bureaus, of which eighteen can be called primarily scientific. From the point of view of numbers of personnel and size of budget, the scientific services under the Department of Agriculture stand first in the list. The work of that department is spread through a great number of agricultural experiment stations. With the exception of the Forest Products Laboratory in Madison, Wisconsin, and certain activities which touch on the field of medical research, the Department of Agriculture has not entered into war research to any great extent. Until recently the United States Weather Bureau operated under the Department of Agriculture, but a few years ago it was transferred to the Department of Commerce because of the requirements for better and quicker meteorological information needed for civilian air transportation and by the Army and Navy.

Under the Department of Commerce there are a number of scientific establishments besides the Weather Bureau which are being used extensively in connection with war activities, the most important being the Bureau of Standards. Under the Department of the Interior, the Geological Survey, the Bureau of Mines, and the Bureau of Mineral Statistics and Economics, and under the Department of the Treasury, the National Institute of Health (which is part of the United States Public Health Service) are important scientific establishments contributing to the over-all war effort.

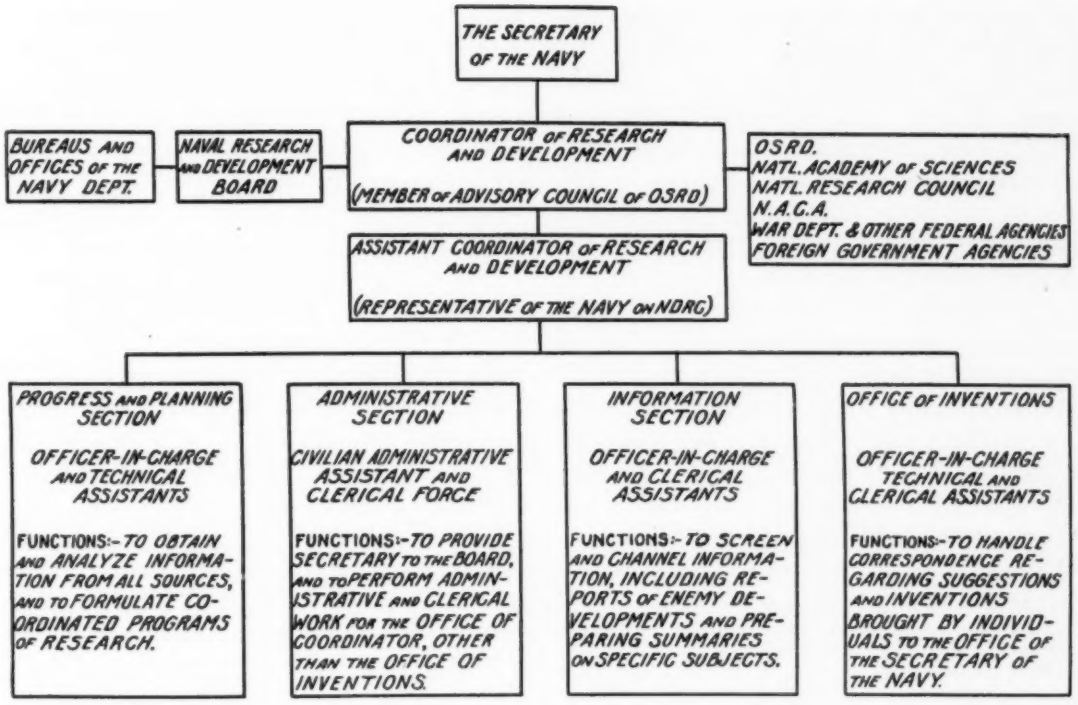
Of particular interest because of its unique character is the National Advisory Committee for Aeronautics, which was established during the last war and which now operates three great research establishments. Until recently the research activities of the NACA were centered in the Aero-Dynamical Research Laboratory at Langley Field, Virginia, but since the outbreak of the war the Ames Laboratory at Moffett Field, California, and the Aircraft Engine Laboratory at Cleveland have been added. No further description of the work done by NACA need be given as this activity was covered in a former issue of the *Journal of Applied Physics*.

Naval Research cannot very well be discussed without mentioning the Army establishments engaged in such work, as the Army and Navy work closely together on new developments. Each branch of the Army has a technical division under which operate laboratories or arsenals where a considerable amount of research and development work is carried on, although their activities consist largely of testing and proving new war materials or equipment. The Ordnance Department operates a proving ground at Aberdeen, Maryland at which is centered most of the proving and testing of ordnance and the research on ballistics for arms of all types. In addition it operates five large arsenals. The Watertown Arsenal is concerned principally with the manufacture of mounts for large caliber guns and is the principal center for research and technical service in the field of metallurgy. The Picatinny Arsenal is devoted to the testing of explosives and the design and operation of pilot plants as guides to the industrial producers. The Rock Island Arsenal carries on research and development in the field of oils and lubricants. The Frankford Arsenal supplements the Aberdeen Proving Ground as a testing and a development center for small arms. The Tank Arsenal in Detroit is the center for the design and testing of tanks.

In the Signal Corps the technical division is divided into three principal branches: the Ground Signal Branch, the Electronics Branch, and the Aircraft Radio Branch. The research, development, and testing work carried on under the Signal Corps are divided principally between the signal laboratories at Fort Monmouth, Camp Evans, Camp Coles, Eatontown, and Toms River. The Signal Corps also maintains a large cooperative establishment working with the Army Air Forces at its principal center, Wright Field.

Until quite recently the research and development work of the Chemical Warfare Service was centered in its great Edgewood Arsenal. When the threat of war came closer, a few years ago, and because a very large portion of the facilities at the Edgewood Arsenal was taken up by production, the Chemical Warfare Service established a subsidiary research laboratory at the newly erected Chemical Engineering Laboratory of the Massachusetts Institute of Technology.

Despite the great expansion of the Army Air Forces, this service has continued to concentrate


THE SECRETARY OF THE NAVY
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COORDINATOR OF RESEARCH AND DEVELOPMENT
(MEMBER OF ADVISORY COUNCIL OF OSRD)
OSRD.
NATL. ACADEMY OF SCIENCES
NATL. RESEARCH COUNCIL
N.A.C.A.
WAR DEPT. & OTHER FEDERAL AGENCIES
FOREIGN GOVERNMENT AGENCIES
ASSISTANT COORDINATOR OF RESEARCH AND DEVELOPMENT
(REPRESENTATIVE OF THE NAVY ON NDRC)
PROGRESS AND PLANNING SECTION
OFFICER-IN-CHARGE AND TECHNICAL ASSISTANTS
FUNCTIONS:- TO OBTAIN AND ANALYZE INFORMATION FROM ALL SOURCES, AND TO FORMULATE COORDINATED PROGRAMS OF RESEARCH.
ADMINISTRATIVE SECTION
CIVILIAN ADMINISTRATIVE ASSISTANT AND CLERICAL FORCE
FUNCTIONS:- TO PROVIDE SECRETARY TO THE BOARD, AND TO PERFORM ADMINISTRATIVE AND CLERICAL WORK FOR THE OFFICE OF COORDINATOR, OTHER THAN THE OFFICE OF INVENTIONS.
INFORMATION SECTION
OFFICER-IN-CHARGE AND CLERICAL ASSISTANTS
FUNCTIONS:- TO SCREEN AND CHANNEL INFORMATION, INCLUDING REPORTS OF ENEMY DEVELOPMENTS AND PREPARING SUMMARIES ON SPECIFIC SUBJECTS.
OFFICE OF INVENTIONS
OFFICER-IN-CHARGE TECHNICAL AND CLERICAL ASSISTANTS
FUNCTIONS:- TO HANDLE CORRESPONDENCE REGARDING SUGGESTIONS AND INVENTIONS BROUGHT BY INDIVIDUALS TO THE OFFICE OF THE SECRETARY OF THE NAVY.

FIG. 1. Chart showing the organization of the Office of the Coordinator of Research and Development.

its research, development, and testing activities at its huge establishment at Wright Field in Ohio. There are, of course, many other centers at which extended service testing goes on, or at which new equipment is installed in aircraft, but Wright Field remains the headquarters for the research and development work of the Army Air Forces.

The principal research establishments of the Navy are described in detail in this issue of the Journal. The need for coordinating the work of these establishments was early recognized and an effort was made in the past to accomplish this through Boards or Committees. Notable attempts to provide coordination in this manner were made by setting up the Liaison Committee for Naval Research which was later followed by the Navy Department Council for Research. The officers assigned to these boards or committees all had other full-time duties to perform with the result that their coordinating work had to take second place. The need for providing full-time machinery to perform this function became even more important with the establishment in June, 1940 of the National Defense Research Committee, followed in June, 1941 by the establishment of the Office of Scientific Research and Development under the Executive Office of the President. The Secretary of the Navy therefore, in General Order No. 150 under date of July 12, 1941, placed the coordination of this work under a Coordinator of Research and Development who reports directly to him. The organization of this office is shown in the accompanying chart, Fig. 1. It will be noted that it includes also the Office of Inventions. This office handles all suggestions and proposals received by the Navy Department either directly or through the National Inventors Council relating to new or improvements of old weapons and devices.

A description of the organization and functions of OSRD and of NDRC appeared in a recent issue of the *Journal of Applied Physics* and need not be repeated here. Suffice it to say that the establishment of OSRD provided the way for mobilizing the scientists of the country for war work. The principal research and development activities of the OSRD are carried on under contracts with appropriate research institutions, these contracts being financed from an annual congressional appropriation. The appropriation

for the fiscal year 1944 amounts to 136 million dollars. There were placed up to November 15, 1943, 1748 contracts, of which 439 had been completed by that date. These contracts were entered into with 250 industrial laboratories and 119 academic research institutions. About 7500 scientists and engineers of professional grade are engaged under these contracts, plus a considerably larger number of assistants and technicians.

Research and development projects undertaken by the NDRC originate for the most part as requests from the Army or the Navy. Some projects are initiated by the NDRC itself or by the director of the OSRD. The requests from the Navy Department must all be cleared through the Office of the Coordinator of Research and Development, who, before submitting them to OSRD, makes an investigation to ascertain whether the work can best be handled by one of the agencies under OSRD, by the National Academy of Sciences, by the National Research Council, or by one of the established Navy laboratories, if this has not already been done in the preliminary discussions leading up to the formulation of the project. He also determines whether more than one bureau is concerned and arranges for the designation of liaison officers by the bureaus to work with the scientists finally assigned to the work.

It is a question whether the greatest service which a coordinator can render lies in getting a research project started or whether it consists of clearing away impediments in the path of progress after it has been started. The latter is particularly important in the case of research that is being carried on by OSRD as distinguished from work that is being handled in a Navy Department laboratory. Coordinating the thinking of the scientists with the practical point of view of the user is of the greatest importance. Arrangements to bring this about are not always easy to make because the using activities are generally so fully occupied with current plans and immediate needs that they do not have much time for studying the potential value of new instruments which have not yet emerged from laboratories.

One of the greatest difficulties encountered by the scientists under OSRD in their work with the War and Navy Departments has been the one of finding their way about in the maze of war-expanded officialdom in Washington. The scientist is normally not acquainted with all of the activities that have an interest in the project on which he is working, but the office of the coordinator has been able to relieve him of the burden of finding out with whom to deal, especially during the early stages of a project. All he needs to do is to get in touch with the coordinator's office to get this information. Once the project is under way and a liaison officer has been designated the scientist gradually becomes acquainted with all of the individuals in the various branches of the Navy Department who have interests in the project.

The wisdom and thoroughness with which the requirements and characteristics of a proposed new weapon or device are formulated have a great deal to do with the progress that can be made in doing the research that is involved. These requirements must be stipulated by the using service sooner or later—the sooner the better. Demanding the impossible must be avoided on the one hand (largely because it takes longer to achieve the impossible than the possible) and lack of appreciation of the relation of possibilities to needs must be avoided on the other hand. While it is not functionally the business of the coordinator to formulate staff requirements, his office has been of great help to the using services in bringing together the minds that are in the best position to do the preliminary thinking leading up to the statement of the problem. This is usually accomplished by preliminary conferences.

The conference method is almost always used during the progress of research to keep all hands in touch with the current situation and to remove any obstructions that are delaying progress. These conferences are generally arranged by the Coordinator of Research and are usually held in Washington in the coordinator's office, but they are sometimes held in the laboratory carrying on the work or in the field where tests of the weapon or device are being made.

Such conferences to be helpful must bring together the right people at the right level. Their principal object is to reach prompt decisions as

to the next steps to be taken and to clear away obstructions. In preparation for a conference a careful agenda is always prepared in order to avoid waste of time in fruitless discussions. The Coordinator of Research initiates most of these conferences, although they are sometimes requested by the research workers or the using activities in the War or Navy Departments. The specialist officer on the coordinator's staff makes the detailed arrangements for the conference, notifies the individuals who are to attend, prepares the agenda, and finally prepares the minutes of the conference. The Coordinator of Research, himself, usually acts as the chairman of these conferences.

The Office of Naval Intelligence is charged with the responsibility for gathering information from foreign as well as from domestic sources on all kinds of naval matters and of distributing this information to the places in the Navy Department where it is needed and where it can be used. Due to the great variety of information which is received, the problem of getting it quickly to the places where it is needed is not an easy one. The coordinator's office is of considerable help to the Office of Naval Intelligence in screening and channeling the flow of this information. He is in a particularly good position to do this because of his contacts with the research and development activities of all bureaus and with outside research organizations. The coordinator's office has in this manner, as well as by reason of the fact that a large library of technical reports of all kinds is accumulating, become a source of information which is constantly being used by the bureaus and by the research activities outside of the Navy for obtaining information as to what has been or is being done in the various fields of research.

"I think no one will argue against the statement that as long as we have a Navy, so long must we have Naval Research. And in my opinion, we shall have to have a Navy, and a strong one, for a long, long time. Having been a technical adviser on two reduction of armament conferences and having observed the tragic results and lack of results thereof, it is inconceivable to me that any victorious power will ever let down its guard again to the extent of crippling its Navy, all arguments about armaments bringing on war to the contrary notwithstanding."

A. H. Van Keuren
Rear Admiral, U.S.N.

Official U. S. Navy Photograph

The U.S.S. NICHOLAS, one of the Navy's 1940 Fletcher Class Destroyers.

Research in the Bureau of Ships*

BY CAPTAIN HENRY A. INGRAM, U.S.N.†

THE vicious character of the present war leaves us under no illusions as to the fanatic bravery of the Japanese warrior. Across the Atlantic our German adversary has excellent weapons which he uses with skill and determination. There is unquestionably a considerable exchange of technical information between them. The successes of our armed forces have been due in no small part to the superior tools of war with which they have been supplied and which have enabled them to advance with confidence in the face of discouraging obstacles.

Every offensive move against our intrenched foes involves successfully contesting the control of the sea lanes. Sea and air power embodied in hundreds of different craft ranging from battleships and carriers to blimps and rubber landing boats are our instruments in this struggle. They are infinitely more complex than their peacetime counterparts. Every detail must cope with the extraordinary stress and strain of battle, the shock of gunfire and tremendous explosions, the impact of shells and bombs, and the ravages of fierce fires. Success depends on the saving of seconds in striking the first blows at the enemy through the precise functioning of the most complex combinations of machinery. Communications must be maintained simultaneously with other vessels, aircraft, and shore stations with the maximum security and facility.

THE DESIGN OF NAVAL VESSELS

The part of the Bureau of Ships in the naval organization is to originate new concepts of vessels for the consideration of the naval command, then to design them and specify their details to the extent required to enable them to be constructed successfully. They are built and equipped in Navy yards or by private contractors under the supervision of the Bureau. Once in service they are maintained throughout their useful life, modernized as necessary, and finally decommissioned and ultimately scrapped under the Bureau's auspices. Other bureaus provide the personnel, ordnance, aircraft, and the supporting shore bases which are intimately related to the activities of the Bureau of Ships.

Harris & Ewing
CAPTAIN
HENRY A. INGRAM

Naval vessels must be skillfully fashioned and constructed of proper materials in all their parts. Superiority in battle demands superior quality in every detail. Rapid ship deliveries require the utilization of mass-production methods. These must be used with a minimum of sacrifice of the all-important aspect of quality.

The ship to be built is described to its builder by plans and by specifications prepared in the Bureau. On the fundamental soundness and completeness with which these are prepared rests the basic excellence of the vessel. The thousands of requirements covered by the specifications and plans must be questioned for each new ship to make sure that changing conditions do not demand revision. Progressive design demands a knowledge of new facts as well as old precepts to justify bold encroachment on the empirical rules which represent past practice. These facts are derived from experience and research.

The basic concept of a ship design originates in the needs, present or foreseen, of the naval service. The Bureau of Ships cooperates with the general board and the other material bureaus to formulate the general characteristics which are required to satisfy the military qualities desired.

* The opinions contained herein are those of the author alone and do not necessarily reflect the official opinion of the Navy Department or the naval service at large.

† At the time this article was written, Captain H. A. Ingram was head of the Research and Standards Section of the Bureau of Ships. Since then he has been transferred to other duties. The present head of the section is Captain Logan McKee.

Extensive model tests are used in developing hull forms and propulsion systems. When these studies achieve a satisfactory compromise with the dictates of nature, somewhat more detailed plans and hull and machinery specifications in great detail are prepared for the guidance of the builder and the Navy's inspectors. A requirement of these ships' specifications is the use of the latest "purchase specifications" covering in exact detail the multitudinous components which must be assembled into the ship. There are in the Bureau's organization a number of technical sections, each of which is expert in one or more of the component parts of the vessel. A list of these technical sections indicates the scope of the Bureau's material problems.

Hull arrangements	Turbines and gears
Structural	Boilers
Welding, casting, and forging	Heat transfer
Damage control	Internal combustion engines
Air conditioning	Piping
Equipment design	Electrical
Minesweeping	Internal communications and fire control
Ship salvage	Gyro compass
Auxiliary machinery	Shore facilities

Radio communication
Aircraft communication
Underwater sound

Among other duties each section is entrusted with the responsibility for incorporating into our ships the latest practical advancements within its specialty, subject to general approval by a separate staff having regard to the ship as a whole. When troubles develop, the technical sections institute a search for a better solution. When new ideas appear they may examine them for their suitability.

THE LABORATORIES OF THE BUREAU OF SHIPS

In order to provide scientifically sound sources of information, the Bureau maintains a number of laboratories which undertake research, develop ideas into suitable form for shipboard use, and test materials for their conformance to naval requirements. These laboratories are different in that they are equipped to deal with problems which are unique to the Navy and the ships of the ocean. They are staffed by naval officers and trained civilian specialists who have intimate knowledge of the practical aspects affecting material of seagoing vessels.

The U. S. naval laboratories are administered either as independent commands or as activities under the commandants of naval districts or navy yards. Each laboratory is placed under the cognizance of that bureau which is most intimately concerned with its principal output. Those under the cognizance of the Bureau of Ships are the:

Naval Research Laboratory, Anacostia, D. C.
David W. Taylor Model Basin, Cárderock, Maryland
Naval Engineering Experiment Station, Annapolis, Maryland
Naval Boiler and Turbine Laboratory, Navy Yard, Philadelphia, Pennsylvania
Industrial Test Laboratory, Navy Yard, Philadelphia, Pennsylvania
Material Laboratory, Navy Yard, New York
Industrial Laboratory, Navy Yard, Mare Island, California
Radio and Sound Laboratory, San Diego, California
Naval Mine Warfare Testing Station, Solomons, Maryland (Under the joint cognizance of the Bureau of Ships and the Bureau of Ordnance).

In addition, there are smaller laboratories serving special purposes as follows:

Paint laboratories at Navy Yards, Mare Island, California, and Norfolk, Virginia
Rubber research at Mare Island, California
Metals Laboratory at Munhall, Pennsylvania
Rope Laboratory at Boston, Massachusetts
Petroleum Laboratory at Houston, Texas
Experimental Diving Unit at the Navy Yard, Washington, D. C.
Industrial Laboratory at the Navy Yard, Puget Sound, Bremerton, Washington.

These laboratories undertake research and testing for any naval bureau and any other government activity as their facilities and work loads permit without regard to Bureau sponsorship. In addition, the Bureau of Ships employs the facilities and talents of other bureaus, other agencies of the government, such as the Office of Scientific Research and Development, and industrial and university research organizations as appropriate. The end products of this research and development are specifications for the component parts of ships and standards for their installation and use.

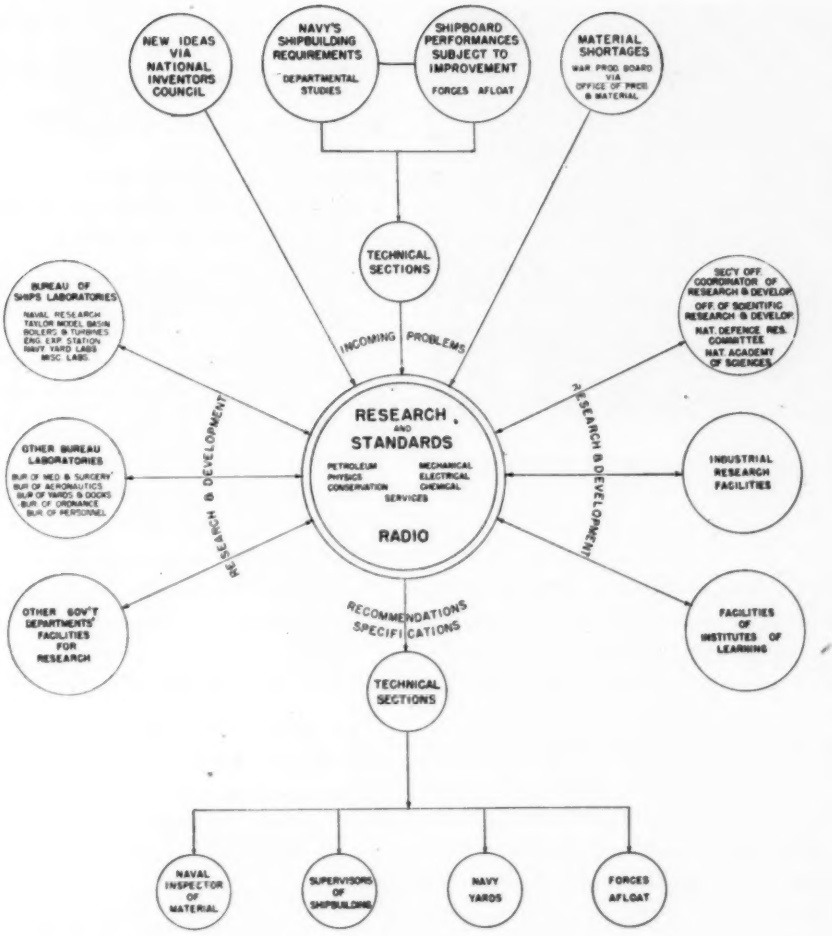


FIG. 1. Chart showing the relation of the Research and Standards Section of the Bureau of Ships with other organizations.

THE RESEARCH AND STANDARDS SECTION

The wide range of interests of the Bureau of Ships and the varied facilities of the laboratories made it essential to establish a section within the Bureau charged with the responsibility for directing and correlating the Bureau's research interests. This is the Research and Standards Section. It searches for needs requiring investigation. It disseminates information derived from research and development. It is the liaison between the sections of the Bureau, its laboratories and contacts with civil establishments in regard to matters of research, development, the establishment of specifications and standards for material, and the technical questions of inspection of the items purchased under specifications.

The fulfillment of these functions requires:

(a) A knowledge of naval service requirements.

(b) A knowledge of the performance of existing material.

(c) An appreciation of possible contributions of science and industry to the solution of naval problems or improvement of material.

(d) Contacts with the Patent Office, the National Inventors Council, and other sources of information on past and current scientific developments in the United States and abroad.

(e) An insatiable curiosity.

(f) A lively imagination controlled by common sense.

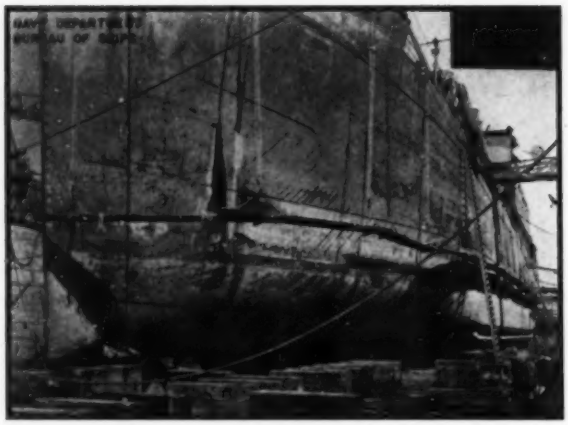


FIG. 2. Hot plastic antifouling paint, after 20 months water borne in Pacific waters.

(g) A wide friendship among researchers and men active in the military services.

(h) A knowledge of the facilities available for research in government laboratories, universities, and industry.

(i) A technical staff to analyze requirements, write directives for research, place research projects in suitable laboratories, determine relative priorities, follow research progress, conduct service tests, criticize reports, and, finally, to crystallize the entire study into specifications for the procurement of material of assured performance on vessels of war. These specifications must be tempered to suit the production facilities available. For this work the qualified personnel of other sections of the Bureau are utilized as their abilities and time permit.

(j) Collaboration with other government agencies, technical societies, and industry in the conduct of research, the development of standards, and broadening of the scope and usefulness of specifications.

In addition, the section undertakes a great deal of work which is outside the scope of any particular technical section of the Bureau. Some items of this work are:

Thermodynamics
Technical control of the inspection of petroleum products
Trouble shooting on shock, vibration, sound, and corrosion problems
Conservation of war critical materials through purchase specification amendments
Analysis of variations in the physical and chemical properties of shipbuilding steels
Statistical analysis of engineering performances and casualties
Preparation of charts relating fuel expenditures to the speed of vessels
Design of ship camouflage
Design of protective coating and antifouling paint systems
Typing, stocking, and distribution of purchase specifications
Preparation of budget estimates for all the above-listed activities.

In order to mobilize a large number of research activities on those particular phases of a specific problem for which each is especially fitted, and to follow their work through to successful conclusion, an agency in intimate touch with the details of the problem and the capabilities of the investigators is essential. The Research and Standards Section of the Bureau of Ships alone is in a position to fulfill that need.

A TYPICAL EXAMPLE

As an example of the functioning of the Research and Standards Section throughout a long-term investigation, the development of antifouling paint systems for ships' bottoms will be described. Presence of the fleet in warm Central Pacific waters during the nineteen thirties resulted in a strong demand for antifouling performance superior to that of the standard Navy paint formula. At the instigation of the Bureau of Construction and Repair (now the Bureau of Ships), the Edgewood Arsenal and the Naval Research Laboratory had previously attempted to determine the characteristics of a fairly satisfactory foreign formulation. The analysis was unsuccessful, but pointed to the merits of a thick "plastic" matrix to carry the toxic constituents, specifically suggesting certain phenol-formaldehyde resins.

The Mare Island Navy Yard developed this lead into a very effective paint, but the problems of applying it at a temperature well above the boiling point of water were a serious drawback. As service experience with this paint increased, the difficulties were analyzed as follows:

(a) Paint adhesion was poor.

(b) Cold weather applications were quite unsatisfactory.

(c) Hot weather applications were troublesome.

(d) Equipment was complicated and considerable skill was required for successful application.

(e) Strategic and critical materials were required.

(f) Costs were excessive.

(g) Reports of all bottom paint performances were generally untrustworthy.

An extensive program of development was undertaken by orders to Navy yards, by requests to the Coordinator of Research and Development for National Defense Research Committee assistance, and by direct contracts for research work. The paint research laboratories at the Navy Yards at Mare Island, California, and Norfolk, Virginia, were given broad general directives to study the hot plastic formulas and application techniques, to effect improvements therein, and particularly to try to develop a plastic for cold application which would have comparable antifouling characteristics. The Industrial Test Laboratory at the Philadelphia Navy Yard contributed to the general study of underwater priming formulas. The Mare Island Navy Yard, Columbia University, and the National Defense Research Committee worked on methods of preparing ships' bottoms to insure paint adhesion. The Woods Hole Oceanographic Institution and the Navy Biological Laboratory at San Diego undertook basic studies of fouling phenomena and the reason for the relative effectiveness of different toxic additions to the paint. The National Defense Research Committee undertook a fundamentally new approach to the problem of antifouling paint formulation. Extensive interchange of information with the British Admiralty was begun. The advisory services of eminent members of the National Paint and Varnish Manufacturers' Association and the American Coordinating Committee on Corrosion were enlisted. A survey of fouling incidence and severity throughout the east and west coastal areas was made, and a new testing station was established in Florida operated by the University of Miami under subcontract from Woods Hole. Here have been found the most accelerated and consistent paint failures. Many suggestions

FIG. 3. Improvement in antifouling paints, after 8 months water borne. Left panel—cold plastic paint. Right panel—hot plastic paint. Center panel—superseded coal tar resin formula.

received from the National Inventors' Council and private sources have been reviewed and a few have been tested.

Widespread service tests of promising developments in paint formulas have been undertaken on buoys, small craft, and larger ships. Statistical analyses of the reports of these tests are made by punch card technique on sorting machines.

As a result of this program, which is as yet far from completed, plastic bottom paints have been improved and the following accomplishments have resulted:

(a) Vessels can remain out of dry dock as long as 18 months with inconsequential reduction in speed or increase in fuel consumption due to marine fouling. With planned scheduling of drydocking periods, much cold weather paint application can be avoided.

(b) Advanced base and continental dry docks are more available for battle damage repairs due to reduced routine docking load.

(c) Fleet demands for fuel are appreciably less (perhaps 10 percent).

(d) Fewer tankers are needed to service the fleet.

(e) Corrosion of ship hulls is notably reduced.

(f) Teredo attack on wood hulls is better controlled.

(g) The need for much strategic material has been eliminated.

(h) The cost of the paint has been halved.

(i) Ships' bottoms are being sandblasted to bare steel, an inhibitive rust treatment applied, and a complete repainting accomplished with minimum expenditure of man power and within the time limits of availability for repairs. The ship's force is spared this "all hands" job, permitting them to take leave or accomplish other repairs.

(j) Four new "cold" formulations are most promising in tests now under way. Two of these are in widespread use.

(k) The fundamental requirements for the design of successful antifouling paints have been established and the problem is no longer a hit-or-miss "witches brew."

(l) Testing techniques to control paint manufacture, insure stability of product, and maintain consistent quality and performance are available and rapidly going into use.

(m) Specifications for open purchase of one of the paints have been distributed.

(n) An educational and training program in the best methods of accomplishing bottom preparation and painting is beginning.

This typical program was not dramatic in its inception and its results are not spectacular. A valuable contribution to our military effectiveness has resulted, but even more gratifying is the thought that it will become of increasing value to ships engaged in peaceful pursuits.

RESULTS OF NAVAL RESEARCH

Research, stimulated by the urgent needs of war, is bringing forth accomplishments of widespread application to the national economy. The needs of the military services result, in most instances, in developments of general usefulness. The naval research facilities, limited though they are to special objectives, are a national asset in the broader sense. They operate in war and peace to afford the nation an unbiased source of information for establishing impartial requirements for those products of industry which are needed for our vital defenses. These are reflected in the Bureau of Ships' *Ad Interim* specifications which subsequently extend their usefulness when accepted as Navy Department specifications. The latter are frequently merged into joint Army-Navy specifications and ultimately into federal specifications. The inevitable results are new standards of quality for national production.

Many commercial products in common use stem from such a developmental trend, among them being medium and high tensile steel and aluminum plates and shapes, electric cables, additive lubricants, high capacity storage batteries, standardized ropes and cordage, and plastic electrical fittings. The research program of the Bureau of Ships will have much more to contribute in the days ahead. Naval research is an indispensable part of both the wartime and the postwar Navy. Fortunately it can be easily justified as it pays dividends in both war and peace.

"The Naval Research Laboratory was born in the minds of such scientists as Thomas A. Edison. Secretary Daniels and I enthusiastically backed the movement to inaugurate a program of research which would build a fleet of great ultimate power. That this was a real inspiration has been proven by the notable achievements of the Laboratory since its opening.

"Your staff of scientists have engaged upon research problems with the indomitable spirit of the Navy. Sometimes these problems have seemed insurmountable, particularly in the field of detection of the enemy. Our success is proven since we are now able to meet the enemy in the air and on the sea with unsurpassed battle intelligence.

"I congratulate the Laboratory on its many achievements and urge its staff of scientists to carry on their unremitting efforts until this war and the peace to come have been won."

FRANKLIN D. ROOSEVELT

The U. S. Naval Research Laboratory*

BY REAR ADMIRAL A. H. VAN KEUREN, U.S.N.
Director, U. S. Naval Research Laboratory

REAR ADMIRAL
A. H. VAN KEUREN

THE Naval Research Laboratory, located on the Potomac River, in Anacostia, Washington, D. C., was established to meet the technical and scientific necessities of the Navy as emphasized by the lessons of World War I. As early as 1910 Thomas A. Edison recognized the necessity for a research organization within the Navy and, assisted by the active support of the Naval Consulting Board, he succeeded in interesting the Secretary of the Navy in the project. As a result of their recommendations, Congress appropriated money in 1916 to establish an experimental and research laboratory, "for laboratory and research work on the subject of gun erosion, torpedo motive power, the gyroscope, submarine guns, protection against submarine, torpedo, and mine attack, improvement in submarine attachments, improvement and development in submarine engines, storage batteries and propulsion, airplanes and aircraft, improvement in radio installations and such other necessary work for the benefit of the Government service, including the construction, equipment, and operation of a laboratory, the employment of scientific civilian assistants as may become necessary . . . ," Naval Appropriation Bill 1916 H. R. 15947. The formal opening of the Research Laboratory was delayed until July 2, 1923, because of the unusual situations arising from World War I. The twentieth anniversary of the opening was celebrated last year with appropriate ceremonies.

The established mission of the laboratory is, "To increase the safety, reliability, and efficiency of the Fleet by the application of scientific research and laboratory experimentation to naval problems." This mission expresses better than does the appropriation act, the present functions of the laboratory. Many of the original projects specified by Congress could not be carried out because of lack of space or personnel and were transferred elsewhere, but in their place have come other pressing problems, and the laboratory has had to grow to accommodate a constantly increasing work load. Today the main plant on the Potomac River occupies 58.3 acres of ground, has an impressive group of laboratories, shops, and administration offices around a landscaped campus and another row of buildings to the southward for the Radio Materiel School. In addition it has an extensive Annex at Randle Cliffs on Chesapeake Bay where seagoing conditions are simulated for testing many types of radio and other apparatus. The present war has of necessity augmented the number of personnel until today we have approximately 1900 scientific, technical, and clerical employees, 1700 instructors and students in the school, and over 200 officers of various grades, including a number of Waves.

Administratively, the U. S. Naval Research Laboratory is under the Bureau of Ships. This Bureau supplies the larger part of the project money that supports the laboratory, but the Bureau of Ordnance and the Bureau of Aeronautics also contribute substantially both in projects and project money. In addition, Congress gives the laboratory an annual appropriation which covers running expenses and salaries of those civil service and contract employees not chargeable to bureau projects. Currently, the laboratory's direct appropriation is about $2,500,000, while the Bureaus' projects total about $10,000,000. New buildings and facilities are provided by separate appropriations or allocations from the bureaus. Occasionally

* The opinions contained herein are those of the author alone and do not necessarily reflect the official opinion of the Navy Department or the naval service at large.

FIG. 1. Administration building.

Congress finances long-range projects by direct appropriation.

The scientific organization is permanent and founded on the policy that the research scientists shall have full authority and responsibility for the accomplishment of their work. Once a problem is considered by the administration and put in a concrete and specific form it is assigned to the research staff. Thereafter the administration avoids interference with the program for solution and in no case attempts to direct the research. In the interest of good administration, the scientific work of the laboratory is assigned in accordance with the special talents of the scientists of each division.

Research divisions, each having a competent scientist as a superintendent, have been established in radio, sound, mechanics and electricity, metallurgy, chemistry, and physical optics. An interior communication division carries on development tests of shipboard equipment. The divisions are subdivided into sections and each of these deals with some definite type of scientific problem. The scientific work is coordinated by the division superintendents and by the technical adviser.

The administrative and liaison work is carried out by naval officers, chosen for their engineering or scientific background. In time of war, reserve officers who have had civilian experience in science or engineering in universities, colleges, industrial plants, or in engineering practice become available in considerable numbers. The majority of these officers, particularly the younger ones, work in the laboratories under civilian control. The higher administrative and liaison offices are filled preferably by officers of recent seagoing experience.

This combination of officer and civilian control has been the policy of the laboratory from its beginning. It has worked harmoniously and effectively because all concerned have realized that the laboratory is a service organization into which must flow renewed operating experience from the service itself, while scientific and technical continuity is assured by permanent civilian administration.

The principal officials of the laboratory as now constituted are given on the next page.

The superintendents are supported by a carefully selected body of scientists, engineers, and technicians, well equipped by education and

FIG. 2. U.S.S. Aquamarine.

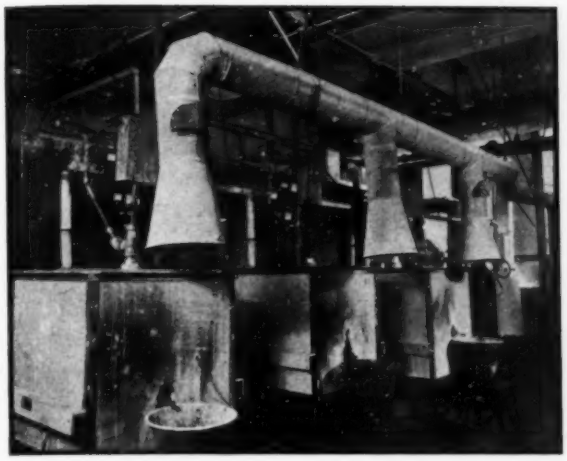


FIG. 3. Oxide manufacturing equipment.

temperament to carry forward successfully difficult and involved physical and chemical investigations. As in the case of most active laboratories, there are more problems pressing for solution than there are men to solve them, so that many of the investigators are given more responsibility and opportunity for independent research than is called for by their rating and salary.

While the laboratory was founded chiefly for purposes of "pure" research, with "applied" research in a naval sense as its secondary purpose, a gradual growth, accelerated by wartime necessity, has been experienced in the direction of development and test work. With so much accumulated knowledge in certain lines easily available to the materiel bureaus of the Navy Department, it is but natural for bureau personnel to desire systems tests made at the laboratory where they may be witnessed and where the Navy's own requirements based on service experience may be stressed, thus insuring a Navy clearance before production in the field has proceeded too far. After the war much of such work will decline and long-range research projects will come more to the fore.

The plant of the Naval Research Laboratory is well adapted to carry on almost any type of scientific investigation. The laboratory is located on tidewater of the Potomac River and is provided with a pier which can accommodate small vessels with a draft of 18 feet or less. A converted yacht is detailed to the laboratory for experimental work in open waters. There are numerous permanent and temporary buildings of harmonious external appearance specially designed to meet definite requirements and having a total

Administrative Staff

Director	Rear Admiral A. H. Van Keuren, U.S.N.
Assistant Director	Commander R. W. Dole, U.S.N.
Administrative Officer	Lt. Comdr. B. M. Fuller, U.S.N.R.
Technical Adviser	Dr. Ross Gunn.
Senior Officer Assistants	Commander J. L. Reinartz, U.S.N.R.
	Commander W. L. Pryor, U.S.N.
	Lt. Comdr. R. H. Bullard, U.S.N.R.
	Lt. Comdr. L. E. Daily (MC), U.S.N.
	Lt. Comdr. P. Talmey, U.S.N.R.
	Lt. Comdr. N. A. Atwood, U.S.N.R.
	Lt. Comdr. C. H. S. Murphy, U.S.N.
	Lt. Comdr. A. C. Packard, U.S.N.R.
	Lt. Comdr. M. G. Dooley, U.S.N.R.
C.O., Chesapeake Bay Annex	Commander K. R. Belch, U.S.N.
C.O., Radio Materiel School	Lt. Comdr. R. Cole, U.S.N.
Manager	Commander M. J. Lawrence, U.S.N.
Supply and Accounting Officer	Commander I. N. Tripi (SC), U.S.N.
Disbursing and Commissary Officer	Lt. Comdr. R. S. Ratcliffe (SC), U.S.N.R.

Scientific Staff

Superintendent, Radio Division	Dr. A. Hoyt Taylor.
Superintendent, Sound Division	Dr. Harvey C. Hayes.
Superintendent, Mechanics and Electricity Division	Dr. Ross Gunn.
Superintendent, Physical Optics Division	Dr. E. O. Hulburt.
Superintendent, Chemistry Division	Dr. Parry Borgstrom.
Superintendent, Physical Metallurgy Division	Dr. F. M. Walters, Jr.
Interior Communication Division	Mr. W. B. Roberts.

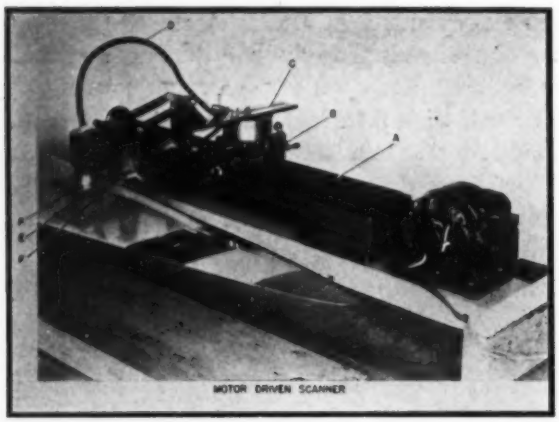


FIG. 4. Eddy current tye flaw detector.

floor area exceeding 58.3 acres. The great majority of these are laboratory buildings, with one large new administration building closing the river end of the campus. The shop facilities for sheet and machine metal working are consolidated in a single large building, with woodworking in another building, and a powerhouse supplies heat and emergency electric power. An enclosed rifle range, 100 yards long, is devoted to special problems in ballistics.

The laboratory buildings compare favorably with the most modern industrial laboratories, being so designed that space may be added to or subtracted from individual rooms by means of portable bulkheads. The administration building houses a well-lighted drafting room in addition to the main office functions.

Among the interesting major pieces of equipment is a large temperature-controlled room in the main shop building, in which the temperature can be varied from $+50°C$ to $-30°C$, with humidity and pressure control features all sufficient to simulate the wide range of conditions which must be met by installations on surface and subsurface ships and in aircraft.

In other buildings there is equipment for shock- and roll-testing all the various apparatus that must withstand the stress of gunfire, explosions, and severe weather.

The present war has emphasized the wisdom of rigorous specifications and tests designed to assure reliable performance in battle, and laboratory equipment and procedure must keep pace with new requirements arising from service experience all over the world. Specifications are altered by the bureaus to take account of such new requirements after tests have pointed the way to the potentialities in each case.

While most of the wartime work load of the U. S. Naval Research Laboratory is of a confidential or secret nature, some of it is a continuation of peacetime programs which have been publicized and which continue to be available to interested industrial organizations on whom the Navy leans heavily for good material both in time of war and time of peace. In this category comes the work of the steel castings section of the Physical Metallurgy Division. Equipped with a modern experimental steel casting foundry, this section continues its investigations on the properties of metals, such as the effect of alloying elements and temperature on fluidity, one of the factors determining the soundness of castings. Considerable work on hardenability, stress relief, and centrifugal casting is also under way. Results of such investigations and research programs are communicated promptly to the industry. The metallurgy division pioneered in the application of radium for the inspection of steel castings and the development of techniques for gamma-ray inspection.

The Chemistry Division likewise carries on a large number of investigations of interest to industry. The chemical and physical properties of fuel and lubricating oils and gasolines are under

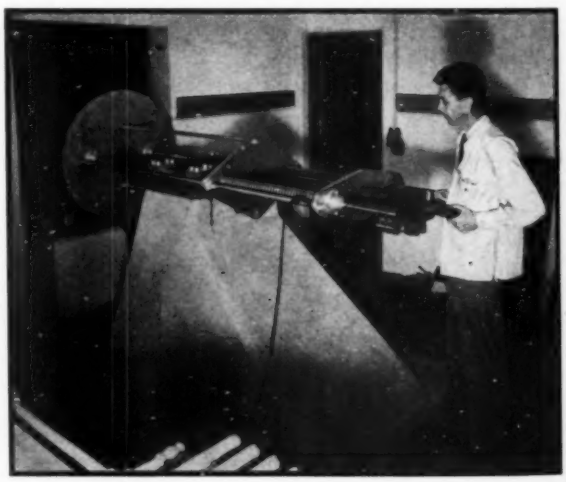


FIG. 5. 37-mm gun and mount.

constant study as, for example, the stability of gasoline in storage with respect to corrosion of storage tanks and the formation of gummy residues. Other problems related to the improvement of storage batteries, self-sealing gasoline tanks, shark repelling fluids for men in the water, the conditioning of air in submarines, the protection of personnel against the possible use of war gases, the measurement of the oxygen content of feed water, the development of paints and protective coatings for naval material, the study of polymers and synthetics, might be taken as samples of the wide variety of work done by this division, some of which may find commercial application eventually.

In the fields of radio, underwater sound, and physical optics, little can be said at this time except that these divisions were pioneers and leaders in their fields and are busily engaged in developing the numerous ramifications that have been stimulated by the war. The same holds true to a large extent of the Mechanics and Electricity Division to which are assigned many interesting new projects.

Much basic research is under way in the field of physical optics. One might mention work on such things as camouflage paints, blackout-lighting, phosphorescent, fluorescent, and radioactive self-luminous materials, use of the electron microscope, photometers, Geiger counters, and many optical developments.

Work of the Interior Communication Division is the development and testing of electrical interior communication equipment used on shipboard by the Navy. Close contact is maintained with the Bureau of Ships and the manufacturers, and valuable suggestions for improvement of both specifications and material are the result.

FIG. 6. Shock and rocker test equipment.

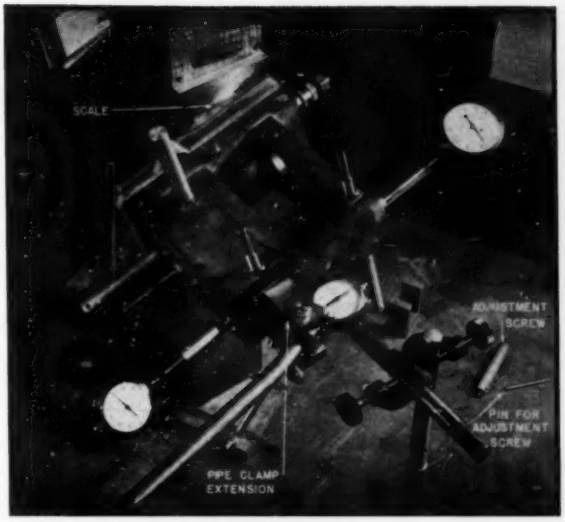


FIG. 7. Scale model test high pressure steam piping.

In addition to the regular divisions of the laboratory, there are special groups of officers and civilians for assisting and advising in the installation and maintenance of special equipment in the fleet. The headquarters of these travelling groups are at the laboratory, to which they return from time to time to inform themselves of latest developments.

One important establishment on laboratory grounds is the Radio Materiel School, established in 1924. This school trains enlisted men, warrant officers, and a few commissioned officers in the maintenance of radio equipment. Its graduates serve a most useful purpose and are in urgent demand in the fleet. Its instructors are officers, warrant officers, and petty officers with recent sea experience with the equipment on which the school gives instruction. The school and the laboratory are in close and constant technical contact and both benefit thereby, the school by keeping in touch with latest developments and projects in the laboratory, and the laboratory by obtaining first-hand experience from the men returning from the fleet and from the criticisms,

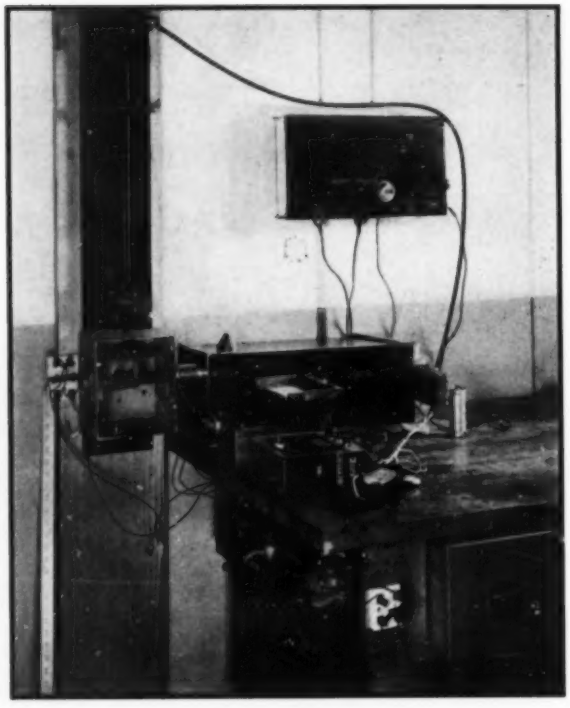


FIG. 8. Elec-potential contact apparatus.

from a maintenance standpoint, that arise during the operation and breakdown of equipment in the school. Barracks and recreational facilities are provided for the students on the laboratory property, likewise for the enlisted women of the Women's Reserve Corps. A considerable number of both officers and enlisted women of this fine organization are detailed to assist in the administrative and technical work of the laboratory and the Radio Materiel School.

While the laboratory is as well equipped and staffed as any in the country, it has no desire to isolate itself from other similar institutions. No one laboratory can be pre-eminent in all lines of research, nor can it afford to overlook the work done in other laboratories along lines in which it considers itself the leader. By means of subcontracts, many phases of our projects are carried out in university and commercial laboratories and a constant interchange of ideas is maintained. The consulting services of outstanding scientists and engineers are retained or sometimes donated by patriotic gentlemen whenever their special talents are desired. Members of various committees of the National Defense Research Committee who work on common problems of wartime application are in intimate touch with naval research laboratory officials and scientists, and frequent exchange visits between their respective laboratories are made. In the national struggle for victory, no source of ideas for the improvement of naval materiel is neglected.

From the foregoing it should be evident that the Navy feels it necessary to carry on a very large amount of research within its own organization, guided by men who are experts in their own fields, and yet have intimate knowledge of the special needs of the Naval Service and frequent contacts with our armed forces afloat, under the sea, and in the air. At the same time the Navy places the greatest reliance on science and industry, not only for the ultimate production of our equipment but for assistance in various lines of research. It has sometimes been argued in the past that the interests of security and secrecy could be better served if the Navy not only did all its research and development within its own service but some of the production work on especially secret apparatus as well. Perhaps this is true, but the disadvantage would be that in time of war the industries would know nothing whatever of our requirements, standards, and special needs, and would therefore be in a very poor position to plunge into greatly expanded wartime production without previous peacetime contact with the Navy. The author believes that the Navy has struck a very fair balance in the matter. Our research and development are very happily related to the industry. Our laboratories serve as a reservoir of naval scientific and technical information available to industry at all times when consistent with the public welfare. If, as has often happened, industry is able to go on with our work into important non-military applications, it is a matter of great satisfaction to the laboratory staff. They like to think that many of the devices on which they have labored not only are carrying destruction to the enemy or protecting the lives of our armed forces, but at the same time have in them the seeds of happier peacetime applications.

The author is indebted to Dr. Ross Gunn and Dr. A. Hoyt Taylor for many sections of this article.

The David W. Taylor Model Basin

By Rear Admiral Herbert S. Howard, U.S.N.
Director, David W. Taylor Model Basin

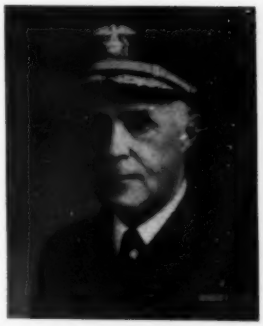
THE largest and most completely equipped ship model testing and experimental plant in the world operates directly under the Bureau of Ships of the Navy Department.

This plant, the David Taylor Model Basin, staffed by a highly trained and capable group of officers and civilian technical and shop personnel, has as its basic function the solving of problems concerning the design and operation of naval vessels by testing models in water under controlled conditions. Included in its work are the determination of the speed and powering of ships, launching, stability, action in waves, turning and maneuvering, and propeller design. Besides questions of pure ship design and form, the problems presented for solution cover the field of minesweeping devices, paravanes, and torpedoes; in fact, everything which has to do with forms which move through the water.

In addition to the preceding problems, special problems of structural design of ships comprise a major activity of the plant. These problems cover all manner of special questions relating to the strength of ships and their parts, the resistance of ship structures to underwater explosions, structural vibration, and the effect of shock, and the elimination of such vibration and shock effects.

In general, the chief function of this organization at present is to give the earliest possible solutions or answers to the wartime problems submitted to it. Research, which has been and is being continuously carried on, gives the background of knowledge which makes it possible to undertake and furnish the solution to these urgent problems.

Although operating directly under the Bureau of Ships, work is carried on not only for that Bureau but for all branches of the Navy Department, whether for the Commander in Chief himself or any of the technical bureaus. Work is also done for other branches of the government, notably the U. S. Maritime Commission, and for private companies and individuals, this practice fulfilling the requirements of the act which created the establishment.



Rear Admiral
H. S. Howard

The construction of the Taylor Model Basin was authorized by Act of Congress of May 6, 1936. This act gave authority for the purchase of a suitable site and the construction of a new model basin establishment for the United States Navy. This was to replace and extend the work of the original Experimental Model Basin which had been in service at the Washington Navy Yard for nearly 40 years. The old experimental basin had become too small to carry out its work for the Navy and private individuals, and its equipment was, moreover, becoming obsolete.

To commemorate the work of that officer who had been responsible for the original Experimental Model Basin and under whom that basin had operated for the greater part of its existence, the Secretary of the Navy directed that the new establishment be known as "The David W. Taylor Model Basin" in honor of Rear Admiral David Watson Taylor, Construction Corps, U. S. Navy, Retired, former Chief Constructor of the Navy.

The location chosen for the new establishment was in the valley of the Potomac some twelve miles from the center of Washington. This site was selected not only because land was available but principally because three basic requirements were fulfilled. First, solid rock was at the surface in this location; this meant that the foundations for the rails of the towing carriages of the basins could be carried down to solid rock and the extremely accurate alignment needed could be practically guaranteed. Second, an ample supply of clean fresh water necessary for the testing basins was available, since the main conduits to

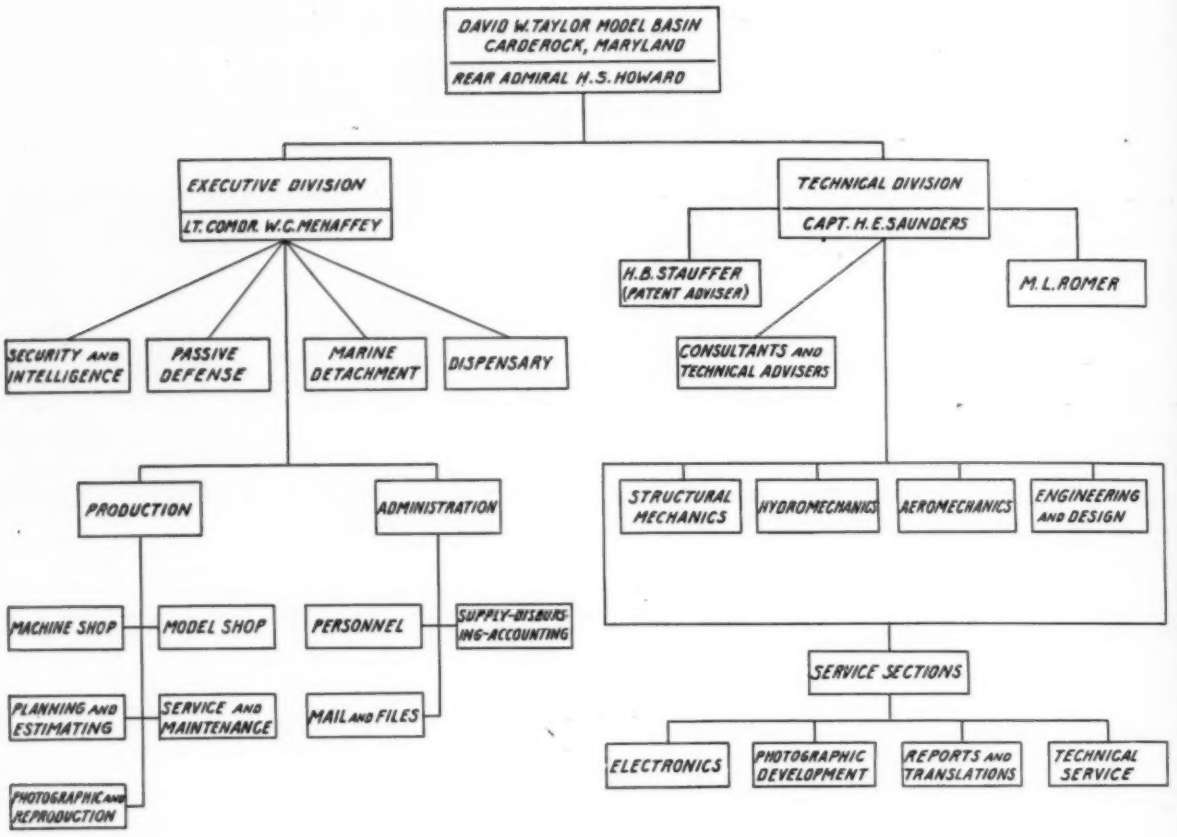


FIG. 1. Chart showing the organization of the David W. Taylor Model Basin.

Washington were close at hand. Finally, the location was away from heavy traffic which might disturb the alignment of the towing carriage rails and their foundations, but it was still fairly close to the Navy Department which permitted easy communication and frequent visits.

The new establishment was planned and laid out by Captain H. E. Saunders, who had been stationed at the old Experimental Model Basin for a number of years. Based on long experience there and reports from model basins the world over, the new model basin was planned to provide not only the best and most up-to-date facilities and equipment for model testing, but in such size and capacity as to ensure, as far as could be foreseen, that it would meet all needs of the Navy for many years to come.

The actual design was undertaken in 1933–34 by the Bureau of Yards and Docks of the Navy Department and construction was started in September, 1937. The basins were filled with water in March, 1939 and the plant was completed in July of that year. Because of the long time required for laying the carriage tracks and for making other preparations, the principal activities were not transferred from the Navy Yard until November, 1940.

The original conception of this establishment, as indicated by the authorizing act, was that it should be constructed to investigate and determine the most suitable and desirable shapes and forms for naval vessels and the investigation of other problems of ship design. Thus primarily the establishment was designed and equipped to carry out experimental work on the forms of ships' hulls and to estimate the power required to drive them, with a secondary interest in other features of design. This original conception has almost been lost sight of in an expansion and

growth far beyond the fields originally contemplated. The war has naturally been principally responsible for this great expansion. Under the heading of underwater forms and propulsion the work has expanded until it has come to cover the proper form or shape of almost any body which is propelled, towed, or projected on or through the water; while under the secondary heading of "other problems of ship design", the expansion has been so broad in the fields of structural strength, shock, vibration, underwater explosions, and related subjects that the primary and secondary objects of the original establishment have almost changed places.

The outstanding features of the Taylor Model Basin are its test facilities, which are unusual both as to types and size and capacity. For an understanding of the work undertaken a general description of the physical plant and these facilities is necessary.

As a testing establishment the Taylor Model Basin was made large enough to house equipment which would accomplish each of the various types of research on models with the greatest degree of accuracy and reliability.

Physically the establishment consists of three buildings: a main building 871 feet by 54 feet; lying parallel to it, a basin building 1330 feet long; and a wind tunnel building. The main building houses in its central section, the offices, drafting and computing rooms, record storage vaults, a library, a photographic laboratory, and a museum.

The western section of the building contains the shops where wood and metal models, mechanical devices, instruments, dynamometers, and other special equipment are made.

The eastern end of the main building constitutes the laboratory. In this laboratory are located the 12-inch and 24-inch variable pressure water tunnels, 30,000-pound and 600,000-pound universal static-load testing machines, and a 150,000-pound alternating-load testing machine, and other equipment.

The basin building is unique in its appearance, because of its barrel arch roof 1188 feet long. Instead of a single large model basin like the old one at the Washington Navy Yard, there are four separate model basins each designed for a particular line of work.

The principal large deep-water basin is 963 feet long by 51 feet wide by 22 feet deep. Here models of large ships are towed or self-propelled. This is the largest basin of its kind in the world.

Joining the large basin is a shorter shallow-water basin 303 feet long by 51 feet wide by 10 feet deep. The depth can be varied at will to represent rivers, canals, and channels of limited

FIG. 2. Naval Experimental Model Basin, Carderock, Maryland. View of building group looking northwest, June 21, 1939.

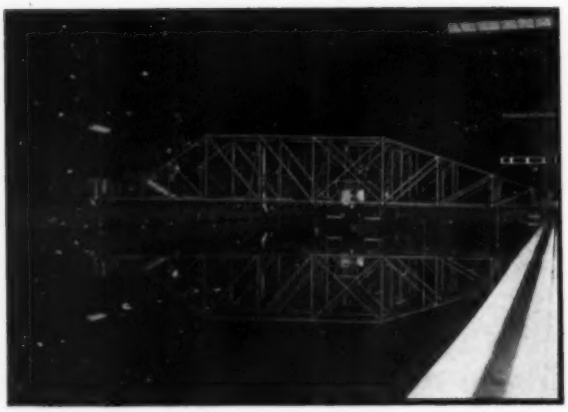


FIG. 3. David W. Taylor Model Basin, July 1941. General view of towing carriage 1 over the deep-water basin with a ship model attached to the towing dynamometer.

depth and width. In this basin models of tugboats, barges, river craft, and other types of shallow-water vessels are tested.

Forming a continuation of the west end of the shallow-water basin is a J-shaped turning basin, for testing the maneuvering and steering characteristics of models. In a special enclosure over this basin, accurate photographic observations of the models under test are made with a group of cameras about 40 feet overhead.

To the north side of the large basin there is a high speed basin 1168 feet long by 21 feet wide by 10 feet deep, for the testing of models of high speed motor boats and seaplane hulls. Incidentally, the site is large enough to permit the extension of this basin to more than twice its present length to meet requirements of the future.

In the basement of the main building is a small basin, 142 feet long by 10 feet wide by 5½ feet deep, for the testing of special models and for unusual research problems.

The towing carriages, which span the basins and operate on the precision-laid rails atop the basin walls, furnish the means of testing the models. The heart of a towing carriage is the dynamometer, which with its related recording instruments measures the forces arising from the motion of a model through the water.

Two carriages are now in operation—carriage 1 over the deep-water basin, and a special quiet-running carriage with wood frame and pneumatic tire wheels over the high speed basin. Under construction, and to be placed in service during 1944, are carriages for the shallow-water basin and the high speed basin. The last carriage will have a top speed of 24 knots.

The carriage which now operates on the deep-water basin is typical. The specifications it must fill are exacting: a testing speed range of from 0.1 to 18 knots, the selected speed to be constant during an 8-second measuring run within 0.01 knot, a rigid frame structure to span the 51-foot distance between the basin walls without permitting disturbing vibrations or deflections at the midspan where the measuring instruments are located, absolutely straight-line motion of the towing point where the model is attached to the carriage, a dynamometer to measure the model resistance during the measuring run to within 0.01 pound but rugged enough to handle the forces on large, 30-foot battleship models at full test speed.

Two variable-pressure water tunnels, designed primarily for testing model propellers but also used extensively for special hydrodynamic tests, are among the unusual facilities. Each water tunnel consists of a closed duct circuit arranged in a vertical plane, in which water is circulated at a known speed. In the lower limb of the apparatus is a motor-driven impeller which circulates the water, and in the upper limb is the test section, fitted with glass ports for visual and photographic observation of the propeller being

FIG. 4. David W. Taylor Model Basin, March 28, 1941. Large model profiling machine in operation. Arm and vertical shaft of the Daniels planer may be seen in the foreground.

tested in a jet of water of uniform velocity and turbulence. The diameter of the jet nozzle is 12 inches for one of the water tunnels, and 24 inches for the other.

The model propeller is mounted on a motor-driven shaft projecting into the test chamber. The thrust and torque of the propeller at various speeds of revolution are measured by a dynamometer. Water speeds in the 24-inch tunnel up to 35 knots are available.

Vacuum pumps lower the air pressure above the water in the test chamber of the tunnel, in order to create an absolute pressure on the model propeller corresponding to the combined effect of atmospheric and water pressure on the propeller of the full-sized ship. Under these conditions, the phenomena of cavitation occur on the model propeller so that the test accurately represents the behavior of the full-scale propeller. Cavitation is the formation of water vapor cavities, or "bubbles," on the propeller blade surface, caused by high loading and consequent serious reduction of pressure on the back, or "suction side" of the propeller. Efficiency suffers when cavitation occurs. Cavitation effects are studied by means of stroboscopic illumination of the propeller being tested, and these effects are recorded by high speed flash photographs, of 1/30,000-second exposure.

In the laboratory building there are located two large machines for testing structural specimens, both full-size and model scale. One, the 150,000-pound alternating-load testing machine, tests beams, columns, riveted and welded joints, and other structural members in alternate compression and tension over long periods of time, to discover the manner, loading, and number of cycles of failure in fatigue.

The other large testing machine is a universal static-load testing machine with 600,000-pound capacity in either tension or compression. Stress-strain data, yield point, and ultimate strength of a wide variety of structural specimens may be obtained with this apparatus.

One of the most unusual and recently completed facilities is the test pond for underwater explosion tests. This is a pentagonal pond, dug partly out of the solid rock and partly formed by built-up rock embankments. It is roughly 150 feet across and will carry water to a depth of 25 feet. In this pond research investigations of underwater explosions and explosive tests against models of ships structures are carried out.

FIG. 5. David W. Taylor Model Basin, August 20, 1941. Weighing a ship model preparatory to ballasting it to the proper displacement, draft, and trim. All models as constructed are sufficiently light to permit adding ballast weights to make their weight correspond to the probable range of ship displacements.

Information can be obtained on the trajectories of model bombs and torpedoes after impact with the water surface by experiments made in the new transparent-wall tank, using high speed motion pictures to record the paths of the models. The new tank has glass windows forming one side and one end; it is 25 feet long, 9 feet deep, and 4½ feet wide, filled with continuously filtered, crystal-clear water to insure clear photographs. The glass windows are three-quarters of an inch thick "tempered" glass, four times as strong as ordinary plate glass of the same thickness. Intense photographic illumination is necessary to obtain good film records of the objects moving through the water.

The circulating water channel, now nearing completion, is an unusual hydraulic testing facility, both as to type and size. Essentially it consists of an open top test section 22 feet wide and 60 feet long in which a stream of water 9 feet deep flows at a maximum speed of 10 knots. The object under test will be held stationary in the moving stream and the forces exerted by the water measured by suitable dynamometers. The walls and bottom of this channel contain windows approximately 4 feet by 1½ feet through which

FIG. 6. Placing ballast weights into ship model to obtain proper trim and even keel.

both visual and photographic observations can be made.

The chief advantages obtained by testing in the circulating water channel are that the object undergoing test can be viewed and photographed from all sides and that the tests may be carried on for an indefinite period without stopping as at the end of a straight towing run.

The objects tested in this channel will consist of ship models, torpedo shapes, mines, and special devices which cannot be tested as well by towing in still water. The water channel will complement the existing turning basins and water tunnels but will not supplant them.

In order that such a large stream of water may be circulated at constant speed with uniform flow throughout the test section, a structure about 150 feet long and 45 feet high is required. The water is pumped through the channel by two 12½-foot diameter propeller type pumps driven by direct connected 1250-horsepower electric motors. These motors rotate at constant speed and the rate of flow of the water is regulated by adjusting the pitch of the propeller blades while running.

The wind tunnel building is located to the west of the main building. It contains two steel wind tunnels, each with a closed rectangular test-section 8 feet by 10 feet, and with single return passage. These tunnels are equipped with 4-bladed, 16-foot diameter wooden propellers, one driven by a 1000-hp motor, the other by a 700-hp motor. These motors are controlled by the Clymer system which permits speed control within plus or minus ½ percent. Air velocities can be varied from approximately 10 to 220 miles per hour. Six precision scales automatically record the three moments and three forces on the model. A seventh scale records the wind velocity.

Airplane models up to 8 feet wing span can be tested both for normal performance characteristics and for stability in yaw; two separate systems for supporting the model are used for these two types of test.

At the present time tests for the Bureau of Aeronautics are still carried on principally in the old wind tunnels at the Washington Navy Yard, but within a short time the new tunnels will be actively operating.

The organization of the Taylor Model Basin is shown on the chart. Rear Admiral Herbert S. Howard, U.S.N., is Director; Captain Harold E. Saunders, U.S.N., who laid out the establishment and was in charge of the entire work of preparing the facilities for operation, is Technical Director and Head of the Technical Division; and Commander W. C. Mehaffey, U.S.N.R., is Executive Officer and Production Officer.

The heart of the organization and the reason for its existence, rest in the technical division. This division is divided farther into three main divisions: hydromechanics, structural mechanics, and aeromechanics.

Each of these divisions is headed by a senior officer, with officer assistants, specially trained and qualified for this particular work. The civil technical staff is of the same high caliber, the nucleus of this staff possessing a national and international reputation in this highly specialized work.

In the hydromechanics division the principal work falls within the field of ships' lines, propellers, and underwater forms such as mine-sweeping gear and torpedoes. After the technical design of a device is completed, a model is built to scale, in order to carry out the test necessary to check the form and to determine the power needed to propel or tow it; the test is made in one of the various model basins. The procedure in a typical test of a ship is as follows.

The usual ship model is about 20 feet long, hollow, and fashioned from layers of wood glued

together. It is carefully shaped to represent the outer surface of the ship's hull, to exact scale, from keel to deck. The model is complete as to its underwater form, with rudder, propellers, shafts, struts, bilge, and docking keels, but without upper works.

The model is first towed, non-self-propelled, over one of the main basins by the carriage which has already been described.

In making a towing run the carriage starts from rest, and smoothly and gradually acquires the speed necessary for the test. When the carriage is towing the model at a uniform rate at the desired speed, and the model is producing its characteristic wave formation, the actual resistance of the ship model in pounds and hundredths of a pound is measured.

Later a second, self-propelled test is run, in which the model is driven under its own power along the basin with small model propellers. Small electric motors installed in the model, one motor to each shaft, operate the propellers. An operator on the towing carriage to which the model is attached regulates the speed of the model ship. From the tests so made, calculations give the corresponding results for the full-sized vessel.

Under the hydromechanics division is also carried out the design of propellers in connection with the Bureau of Ships, and the testing of model propellers based upon these designs. These model tests are made in one of the two propeller tunnels already described.

This division also carries out full-scale special tests aboard ships of the fleet, usually at the time of their trials, such as turning trials to determine the track of a ship under different conditions of speed and rudder.

The structural mechanics division is concerned with all questions of the strength of ships' structure, vibration, and related subjects.

The work in structural mechanics at the model basin had its inception a number of years ago in the thought that if the performance of full-sized ships could be accurately forecast through experimental work with models in a model basin, it should equally well be possible to forecast the performance of the structure of ships by the use of accurately constructed models, with proper technique in carrying out the tests. This would permit gaining knowledge as to the performance of such structures long before a ship itself were finished.

FIG. 7. Engineer using dynamometer for measuring model resistance.

This work was started with elementary models of the hulls of ships, and sectional models of the hulls of submarines. Proving successful, it has been continued to the present time, until it now includes deck and bottom structures, turrets and their foundations, and similar projects.

The next problem undertaken in this field was the resistance of the structure of ships to underwater explosions. It was soon found that, for this work to be effective, fundamental knowledge must be gained as to the nature of the underwater explosions themselves. With the construction of the new Taylor Model Basin an extensive research program was taken in hand to investigate the effect of the explosion of small charges against simple diaphragms, and also to study the explosions of charges themselves, by the use of extremely high speed underwater motion photography. From this research, information is being gained as to the nature of explosions themselves, and their effect upon the structure of ships.

A third most important work of this division is that of investigating vibration of ships' hulls and structural foundations, including support of instruments and other equipment aboard ship. Some of this work is done at the model basin but a large part of it is carried out aboard newly

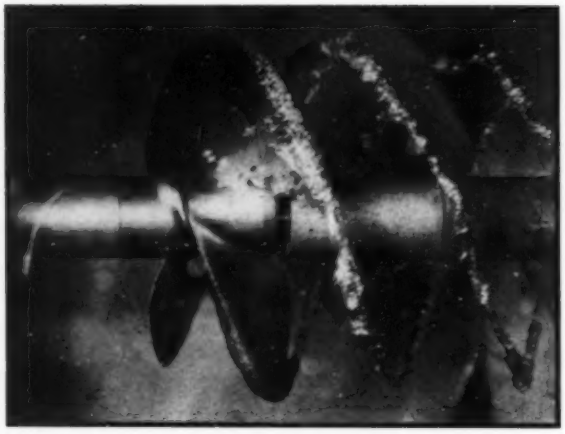


FIG. 8. David W. Taylor Model Basin. Cavitating model propeller under test in 12-inch water tunnel. Picture made with 1/30,000-second flash. Note heavy tip vortices, considerable laminar cavitation near tips, and the start of burbling cavitation of the blade face near the hub. This is a right-hand propeller and the water is flowing from left to right.

commissioned ships of the fleet when undergoing their first high speed runs and gun firing trials.

The work of the aeromechanics division, including the operation of the two new wind tunnels, is concerned principally with wind-tunnel tests of models of new designs of airplanes for the Bureau of Aeronautics of the Navy Department, and with tests to determine the effects of modifications to improve the performance of existing designs. Wind-tunnel tests are also made for the Bureau of Ordnance, and other government departments, to assist them in special problems requiring aerodynamic information.

To construct the various types of models which are used in the investigations which have been described, two separate shops, one woodworking, the other metalworking, form an integral part of the establishment. The former exists particularly to manufacture the wood models of ships, aircraft, or other forms which are tested while the latter constructs all special equipment, instruments, and other gear as well as any metal models used in the tests in the establishment.

In its highly technical work which, in many of its aspects, involves the measurement of infinitely small units of time, stress, and motion, the Taylor Model Basin has taken a leading place in the development of special instruments. As two examples in the field of instrumentation in which the organization has become preeminent, the work in ultra-high speed motion pictures and electronics should be mentioned. The basin has taken a leading position in the development of high speed motion picture equipment and technique to record the details of lightning-fast phenomena such as shock and explosion, and also in the development of electronic measuring instruments accurately to record super-high speed events such as the pressure curve of an explosion, or to measure infinitesimally small changes in displacement for obtaining data on vibrations and strains in structures.

From the preceding paragraphs it can be seen how large a part the work at the Taylor Model Basin plays in the technical side of the war effort. Every new design of ship, from aircraft carrier to landing barge, is checked and tested as to its form and power; minesweeping gear, insofar as its performance in water is concerned, is tested and run in model or full size; special weapons and devices which operate in or on the water are designed as to their hydrodynamic features; and the vibration of new ships and their ability to withstand shock are investigated. The list could be multiplied indefinitely.

This general description of the work undertaken and now underway at the Taylor Model Basin, and the special items listed, would not be complete without comment upon the quality of the technical reports which make available for use the actual results from these tests and projects. No matter how thorough and complete the technical studies and tests themselves may be, if they are not so written up and presented as to be understandable and clear for the use of the officials for whom the tests and studies are made, they might as well not have been made at all. Particular effort has been taken in the preparation of better and clearer reports by progressive development of reproduction methods, layout styles, and writing technique, so that these reports may be readily understandable by those who desire to use them. The success of these efforts has been made evident in the widespread demand for Taylor Model Basin reports throughout this country and abroad as well as by the various agencies of the Navy itself.

At present every effort of the Taylor Model Basin staff and its facilities are being applied to

the one end which is to contribute to the maximum of their abilities to the early winning of the war. Pure research must take a secondary place, but it is only through the pure research carried on in peacetime and the skill so developed in the solving of similar problems that quick and correct answers can be found now for the urgent problems of the war.

The interest of the country in research has increased greatly in these most recent years. It is greatly to be hoped that when peace comes again this interest will not lag but will continue so strongly that this establishment may continue to operate at its full capacity, so that through the more extensive pure research then possible, technical improvements in the design and construction of our ships and naval weapons may increase. Thus should war ever again be forced upon us, we may feel that we have kept ourselves prepared to meet the technical problems of that day.

"Science is a mighty ally of freedom—its advance has brought much release from drudgery and from want. However, we must progress still further. For better machines are not all that is needed to make a better life. We shall have a better world only to the extent that our social thinking and our social progress keep pace with the advance of physical science.

"We are approaching the days in this struggle when the basic challenge of the post-war years will become sharper and clearer. It is a challenge that will ring out to people in all walks of life; to brains and initiative, to cooperation of government and industry, to labor and management, to religion and education. The answer will be found in the minds and hearts of men and women intent upon preserving civilization, and a world at peace. . . . Let us be thankful that America and her Allies have the strength and determination to hold high the eternal torch of freedom. May the victory be a victory of lasting peace, so that out of the bombed and shell-torn earth will come a happier tomorrow for all mankind."

DAVID SARNOFF
Science, November 19, 1943

Naval Boiler and Turbine Laboratory

BY CAPTAIN C. A. BONVILLIAN, U.S.N.
Director, Naval Boiler and Turbine Laboratory

THE Bureau of Steam Engineering of the Navy Department instituted, in 1909 in the Navy Yard, Philadelphia, the Fuel Oil Burning Testing Plant primarily for the purpose, oddly enough, of remedying the hazards involved when using fuel oil for steam generation in naval vessels. That plant consisted of a single building housing one boiler. The Naval Boiler and Turbine Laboratory, as presently constituted, is grouped within thirteen buildings including ten separate firerooms, two auxiliary machinery rooms, a condenser house, a forced-draft blower house, an evaporating plant building, chemical and refractory laboratories, an Oil Burning School, storage rooms, twenty-six oil storage tanks, and seven feed water storage tanks. Until 1932, the Laboratory was known as the Fuel Oil Testing Plant and from 1932 to 1942, as the Naval Boiler Laboratory. The Naval Boiler and Turbine Laboratory now comprises three subordinate divisions, the Refractory Laboratory being authorized in 1915, the Fuel Oil Laboratory in 1934, and the Turbine Test Laboratory in 1942. An oil burning school established in 1943 functions primarily for war training on the same general basis as a precursor during—and for a time after—the last war.

FIG. 1. General view of Naval Boiler and Turbine Laboratory.

CAPTAIN
C. A. BONVILLIAN

The Naval Boiler and Turbine Laboratory is located within the limits of the Navy Yard, Philadelphia, and forms a division in the industrial department thereby permitting utilization of the personnel and equipment of the several shops. The laboratory functions under directives of the Bureau of Ships, Navy Department. It is staffed by a group of naval officers and civilian personnel with necessary technical qualifications for prosecuting the laboratory's highly specialized functions. Administration is vested in a naval officer named by the Navy Department and designated as Director.

The Naval Boiler and Turbine Laboratory serves the fundamental purposes of providing personnel and facilities for full scale testing of boilers for use in all steam driven—or steam auxiliary equipped—naval vessels with primary emphasis on designs for combatant vessels. The turbine testing plant was established to expedite parallel development in turbines and other units comprising ships' main propulsion machinery. Boiler and turbine testing is of such a complicated nature and requires such a large number of specially installed instruments that satisfactory testing on shipboard is impracticable. Corollary to these functions, extensive research work is also carried on in connection with the suitabilities of fuel oils and refractories for use in naval boilers and extensive special developments are actually prosecuted.

BOILER LABORATORY

The equipment and facilities of this section are considered unique in that they constitute the sole United States governmental agency by which

full size boilers of marine design can be tested under fully controlled laboratory conditions while operating at maximum designed steam output, pressure, and temperature. Dual feed water, fuel, and condensate systems make possible the conduct of independent tests of two boilers simultaneously as well as permitting test of boilers at higher capacities, pressures, and temperatures than those presently in service use.

One boiler of each type purchased under contract is subjected to complete examination involving determinations of evaporative efficiencies; optimum combustion conditions for a given steam demand, i.e., speed, steam quality, and consequently efficacy of steam purifying devices; temperature and pressure gradients of the circulating fluids, i.e., air, water, steam, and products of combustion; and effectiveness of the soot blower system. Rapid speed changes are simulated to demonstrate the ability of a boiler to withstand thermal shocks.

Experimental boilers have been procured by the Bureau of Ships for testing to provide bases for advancing requirements.

This section also is concerned with test and development for naval use of equipment associated with boilers such as de-aerators, fuel oil burner assemblies, economizers, air preheaters, soot blowers, safety valves, and various boiler control and indicating instruments and devices. Also tests of h.p. steam valves, pneumatic and hydraulic valve operating gear, and lightweight hose connections are illustrative of some of its other varied activities. The determinations of friction losses in steam and water systems have served to improve the designs with respect to space and weight requirements.

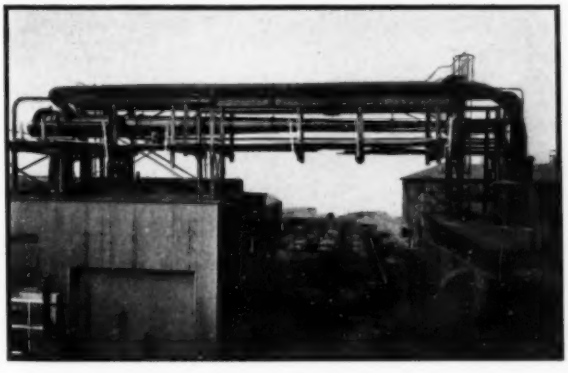


FIG. 2. Venturi for steam flow measurements. Part of fuel oil storage in background.

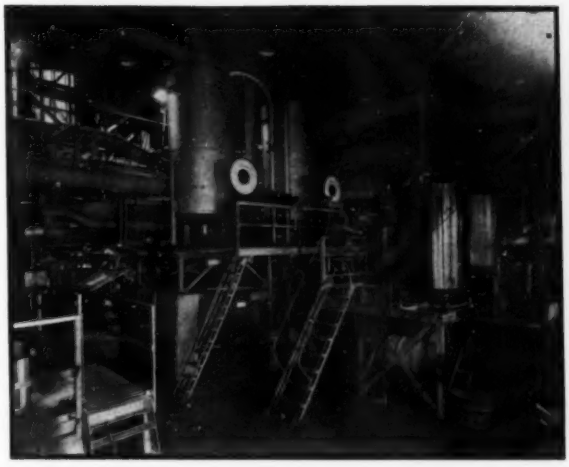


FIG. 3. Oil and feed water weighing systems.

REFRACTORY LABORATORY

The Refractory Laboratory is equipped with facilities for conducting simulated service tests of refractory brick, furnace insulating brick and materials, refractory cements and mortars, insulating refractories, refractory anchor bolts, and other furnace materials. Facilities are available for determination of pyrometric cone equivalent, thermal conductivity, modulus of rupture, and volumetric changes. Measurement and maintenance of temperatures up to 3000°F are required for this work. A 2000°F electric furnace, a 2600°F gas furnace, and a 3000°F gas furnace together with necessary control equipment and instruments also are employed for test purposes.

Refractory materials are built in a panel forming the sides of a specially designed furnace. Furnace temperatures of 3000°F are maintained until heat equilibrium is reached, this to establish the refractoriness and the vitrification tendency of such material. Spalling tests are conducted in another furnace where thermal shocks are imposed by alternate heating and cooling.

FUEL OIL LABORATORY

The directives of the Fuel Oil Laboratory require keeping abreast of refinery technique as it

FIG. 4. Multiple-point recorders with jacks mounted on truck.

affects Navy fuel oil, keeping informed on the quality of Navy fuel oil being currently delivered to the various units of the fleet, and the recommending of operating instructions and/or design changes necessitated by changing fuel oil characteristics. In fulfillment thereof, this section has obtained or has developed the requisite laboratory equipment for complete examination of fuel oil, coal, pulverized coal, and coal-in-oil mixtures. Special apparatuses have been developed for determination of heater-fouling, bunker-sedimentation, and compatibilities of fuel oils. In addition to routine physical and chemical specification tests, fuel oils are further examined for ultimate analysis, heat content, asphalt content, ash constituents apropos fireside deposits and slagging of refractories, and ability to withstand adulteration with sea water.

This section also is concerned with heat transfer as related to fuel oil heater designs. Heating capacity, pressure drops through the oil and steam sides, resistance to fouling, and facility of cleaning are factors considered in the establishment of the acceptability of a fuel oil heater for naval use. Friction losses in fuel oil systems are determined especially in regard to pipe lines, pumping, transfer, and damage control problems. Such specialties as fuel oil combustion agents, sludge dispersers, and soot removers come under its cognizance. It also serves as an analytical laboratory to the other sections.

TURBINE TEST LABORATORY

The recently authorized Turbine Test Plant comprises one room 165 feet by 192 feet. Upon completion, facilities will be available for the first time for the full scale testing of a complete propulsion unit including turbine, reducing gear, and allied auxiliaries. Water-cooled brakes serve as the power measuring devices.

NAVAL TRAINING SCHOOL—OIL BURNING

This school serves principally to instruct enlisted personnel in the proper method of handling boilers aboard naval vessels. Actual operation of the boilers installed at the Naval Boiler and Turbine Laboratory provides the basis for this training. The course of instruction runs for six weeks. The school has been gradually enlarged up to its present 600-student body and is operated over a twenty-four-hour period.

Cooperative work with other government laboratories constitutes a relatively small portion of the Naval Boiler and Turbine Laboratory's activities, particularly in regard to marine boiler testing as was previously mentioned. In this connection the laboratory functions to provide suitable comparison of the performances of competitive designs for use by administration in complying with regular requirements for competition purchase and permits determination of compliances with contractual guarantees. Further, if unsuitable designs are installed in a

FIG. 5. Refractory laboratory showing furnaces and test panel.

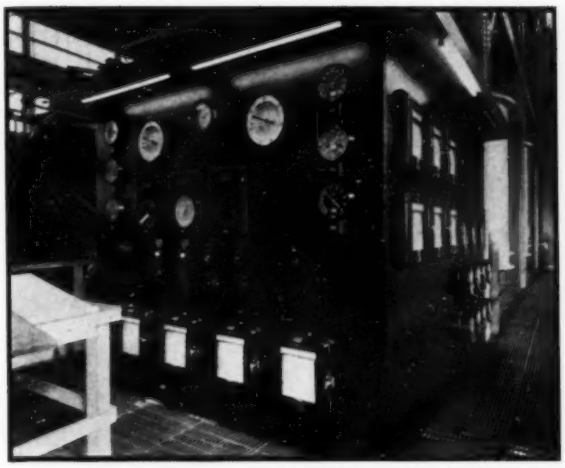


FIG. 6. Control panel in turbine laboratory.

vessel before the unsuitability is discovered, more or less complete rebuilding of the vessel may be necessary. Knowledge concerning design of boilers is simultaneously under constant accumulation by this means; its judicious application renders possible continuous improvement in Navy steam engineering. These investigations provide design data for further increases in boiler capacities without weight and space sacrifices, at the same time providing equal or increased margins of safety in circulation. Consequently it follows that the Naval Boiler and Turbine Laboratory cooperates primarily with the manufacturers of boilers and its accessories. It is believed that the Turbine Testing Plant eventually will serve the same purpose for the complete propulsion units.

In the case of the fuel oil and refractory sections, liaison is maintained between the various companies' research laboratories for the development of products of superior utility to the Navy. Acceptable lists of approved products, formulated at the Naval Boiler and Turbine Laboratory, provide the basis for their procurement. Personnel of these sections also are members of technical committees on petroleum and refractory materials.

The Naval Boiler and Turbine Laboratory is justifiably proud of the distinguished part it has played in boiler development and in its contributions to the technology of fuel oils and refractories. Due to the Navy Department making available this laboratory's facilities, power outputs of naval boilers during the last two decades have more than doubled with no increase in weight and space requirements and thermal economies second to none have been made a reality. The laboratory anticipates sponsoring or assisting in the development of still greater advances in years to come.

The U. S. Navy Radio and Sound Laboratory

BY CAPTAIN P. H. HAMMOND, U.S.N. (RET.)
Director, U. S. Navy Radio and Sound Laboratory

FACED with expanding naval activities and the consequent need for such a laboratory on the Pacific coast, the Secretary of the Navy on June 1, 1940 established what is officially known as the U. S. Navy Radio and Sound Laboratory, San Diego, California. While by virtue of its location its military administration is under the cognizance of the Commandant of the Eleventh Naval District, whose headquarters are at San Diego, the technical activities of this laboratory are in general directly under the cognizance of the Bureau of Ships.

Briefly, the initial mission of this laboratory, with respect to radio, underwater sound, and other equipment under the cognizance of the Radio Division of the Bureau of Ships, was:

(a) To provide expert technical assistance to fleet or unit commanders;

(b) To study, investigate, and report to the Bureau of Ships on suggestions for new or improved equipment submitted by the fleet;

(c) To perform technical work, conduct technical investigations, and work on the solution of such problems as may be assigned by the Bureau of Ships;

(d) To provide technical experts and equipment to units of the fleet which are assigned experimental work requiring the services of such experts or equipment;

(e) To install new and experimental types of shipboard equipment and to conduct tests of this equipment;

(f) To cooperate with the Naval Research Laboratory and assist as may be required in the conduct of any work for which this laboratory may be particularly well fitted by virtue of its location;

(g) To cooperate with engineers or civil or government laboratories engaged in naval work in this area;

(h) To make repairs and alterations to equipment when such require the services of specially trained technical personnel not otherwise available;

(i) To provide technical assistance as may be required by Navy yards or other shore establishments of the Navy engaged in the manufacture, test, inspection, or installation of naval equipment;

(j) To maintain a staff of civilian and naval technical personnel and equipment and shop facilities such as may be required in order to provide the above services and facilities.

CAPTAIN P. H. HAMMOND

The above assignments make it readily apparent that the Radio and Sound Laboratory is not exclusively a research institution; as a matter of fact, ordinarily only a part of its time is devoted to pure research projects. It is, actually, a pool of experienced engineers and personnel, specialists in their fields, with facilities at their disposal to carry on such work as is assigned by the bureau and, in addition, it is the activity to which local problems are referred when technical personnel are not available, or, if available, when they find it necessary to consult highly specialized personnel for the solution. Such a composite mission as that already stated as the foundation of the laboratory requires for its fulfillment a versatile staff, capable of basic research when necessary, but, and of greater importance, well qualified in all forms of installation, testing, and servicing, and intimately familiar with naval equipment, naval communications, and the naval organization in general.

In an activity of this nature the organization need not be particularly unique; it follows in general the typical naval organization plan. The director is the nominal head of the laboratory; an executive officer is his assistant for military, maintenance, and personnel administration. For technical administration, there are two "departments," Radio and Sound, each under a de-

partment head responsible to the director. All four above-mentioned positions are filled by officers of the regular Navy or Naval Reserve. The radio department is composed of three "divisions:" Communications, Radar, and Ultra-High Frequency, each headed by a civilian engineer or physicist. The number of personnel in the various divisions has of necessity been stabilized by this time; while the initial intention was to expand with the volume of work assigned to the laboratory, the manpower situation and lack of space has forced a status quo.

Integral parts of the laboratory, from a technical viewpoint, are the various facilities, which include the secretariat, filing section, stock department, machine shop, woodworking, and metalworking shops. Insofar as possible, these make the laboratory a self-sufficient activity.

Founded in time of peace, albeit during the period of national emergency, the potential value of such an activity as this, located on the Pacific coast, has constantly increased with the declaration of war and the impetus given to the expansion of the fleet. The proximity of the laboratory to San Diego Bay and the ocean has made it particularly valuable for the conduct of many problems. Favorable weather conditions are a distinct contribution, in that it is usually possible to conduct field work without undue interruption throughout the year.

Upon its establishment the laboratory was staffed with a nucleus of experienced personnel from the Naval Research Laboratory. These were augmented from time to time as qualified engineers, physicists, technicians, and skilled tradesmen became available; at the present time the total technical staff numbers about fifty. Restricted by the necessity of obtaining only those who are already experienced in at least a closely allied field and who have prospects of becoming adapted to the rather unusual conditions under which work is accomplished at the laboratory, by the limitations in space, and finally by a lack of availability of qualified applicants, expansion in proportion to the potential volume of work that could be assigned to the laboratory is now out of the question.

While not of absolute technical interest, the type of work in which the laboratory engineers are engaged deserves mention. Qualifications are those required by the Civil Service Commission; however, those are only a beginning. Hours, of course, may be long and inconvenient. If a problem involves facilities that are available only on Sunday, or only at night, then the work schedule must be arranged accordingly. If the problem requires that cumbersome pieces of equipment be transferred from the laboratory to a vessel in the harbor, the engineers do it. Field work is done not only ashore, but also on the sea and in the air. When in the field, the radio engineer or physicist is often his own truck driver, linesman, rigger, surveyor, and radio operator. When at sea, in addition to prosecuting his own line of work, dependent on the nature of the problem, he must also be a sailor, or all his time spent at sea goes for naught. In the laboratory he must be a skilled technician, capable of putting theory in practice with wire and soldering iron. With a myriad of test equipments now in use, he must be familiar with their operation; the same applies to all types of radio and sound equipment in use in our Navy. He must keep notes of his activities and collaborate with the head of his division in writing problem reports.

Two years of war have more or less crystallized the activities of the laboratory into these categories: that work done expressly for and by direction of the Radio Division of the Bureau of Ships, and that done in response to calls for assistance from local units, ashore and afloat. Both are closely allied, inasmuch as the laboratory is directed to visit available ships and in this manner to check continually the efficacy of the various types of communication equipment in use, with particular emphasis on the newly developed equipment. However, each of the above categories includes a variety of fields: The work accomplished for the Bureau of Ships, assigned in the form of problems, may be of a nature such as to necessitate considerable research. In this case the requisite personnel are assigned to the problem and follow it to its ultimate conclusion and the final report. On the other hand, the problem may require the laboratory to investigate a device or an invention in which the bureau has become interested and which may have a service application. In this

case laboratory personnel work with the inventor. His device is investigated to determine its practicability or application. If it is considered to be of even potential value, the inventor is aided in perfecting the device and the laboratory acts in a technical liaison capacity between the individual or corporation and the Bureau of Ships. Other problems may involve tests of new equipment, or the development of an equipment to answer a specific purpose. In the latter case the laboratory is told what the equipment is to do; it designs a prototype, ready for the Bureau of Ships to turn over to a manufacturer for production.

Because the Radio and Sound Laboratory was advantageously located and provided readily available space and facilities, when the University of California Division of War Research laboratory was established in San Diego and commenced work on Navy contracts, it was housed in the Radio and Sound Laboratory building. Since that time the scope of the university's work and its facilities have expanded to the extent that it now has its own buildings and occupies considerably more space than the Radio and Sound Laboratory. However, since it is a strictly non-military organization, though located on the naval reservation, the Navy is charged with its military administration and also acts as liaison between the university laboratory and the various local naval units with which it has contact.

Off the record, but a source of considerable gratification to the laboratory engineers, is their service to vessels of the fleet that may be in the area for a limited time. During routine visits to vessels they are often asked for assistance in solving some problem of a critical nature. Regardless of the nature of the problem and the time limitations, they have yet to record an instance of having had to see the vessel leave with its problem unsolved.

Navy Yard Laboratories, Bureau of Ships*

COMMANDER WALTER C. WAGNER, E-V(S), U.S.N.R.

THE Navy Yard laboratories were established to afford the Navy unbiased sources of information where competitive products of industry could be examined as to their suitability for naval purposes. Out of this has come the important responsibility of developing partly satisfactory commercial products to the point where they more completely fill the Navy's needs or to develop new products for that purpose. This function has been so valuable that their activities have spread and they now serve other bureaus of the Navy Department in a similar manner. They have been able to maintain an advanced state of progress in regard to particular Navy problems by means of close coordination with the forces afloat, by taking advantage of industrial developments, and by close cooperation with various technical and standardization organizations and manufacturers in this country and abroad.

The laboratories, operating under the general technical direction of the Bureau, cover to a limited extent the initiation and prosecution of research. Their principal work is development, testing, and standardization, including type and brand approval testing. A great flow of routine inspection tests is required to maintain the desired standards of performance of materials and equipment. The methods of testing used in the laboratories depend upon several factors among them being the time available. The principal types of testing may be briefly described as follows:

(1) Short-time or abbreviated tests which can be performed within a few hours or days and which are used primarily to determine whether or not material submitted for delivery under contracts meets the specification requirements. These are known as inspection tests.

(2) Tests which require special equipment or procedures and which require several weeks for completion. These tests are known as type or brand approval tests and are meant to determine whether or not a given design of equipment is likely to prove satisfactory in the naval shipboard service.

Harris & Ewing
COMMANDER
WALTER C. WAGNER

(3) Tests of an investigational nature, whatever the length of time or equipment involved, which are intended to outline general courses of action in determining specification requirements and methods of standardization.

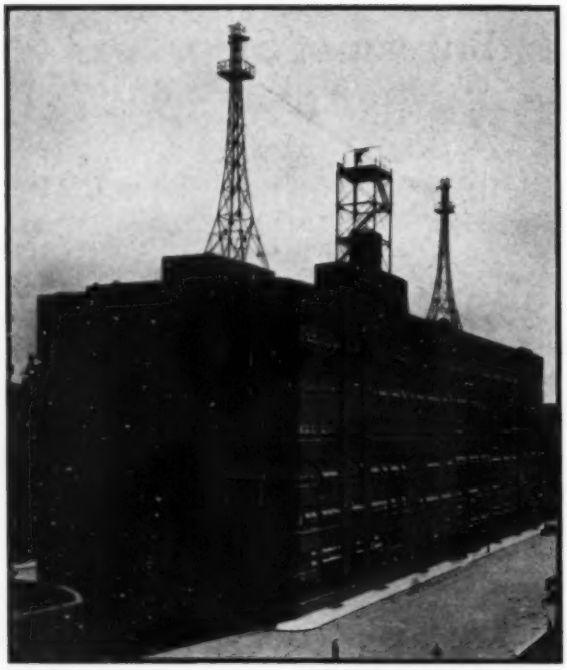
(4) Tests of a developmental character on a given material or application which follow long-range objectives and are intended to simulate shipboard conditions.

An effort has been made to locate the laboratories in relation to the manufacturing centers of the country. Their equipment is particularly suited to inspecting products produced in surrounding areas. This permits more rapid inspection. Two of the paint research laboratories are adjacent to salt water which is a necessity for research in seagoing protective coatings.

The laboratories are also set up in such a manner that, in case of damage, another laboratory can carry on the work of the damaged laboratory without much loss in efficiency or time. A regular exchange of visits of personnel is carried on between the laboratories to insure the workability of this system.

The largest laboratories are at the Navy Yards, New York and Philadelphia. These undertake a considerable degree of research work. The principal function of the other Navy Yard laboratories is to perform work to assist the shops of the yard and the field activities in the solution of special engineering, chemical, and testing problems.

* The opinions contained herein are those of the author alone and do not necessarily reflect the official opinion of the Navy Department or the naval service at large.



Official U. S. Navy Photograph

FIG. 1. The Material Laboratory, Navy Yard, New York, New York

THE MATERIAL LABORATORY, NAVY YARD, NEW YORK, NEW YORK

This laboratory has five main technical divisions: electrical, navigational, metallurgical, mechanical, and chemical, and a general service and clerical division.

The electrical laboratory is the largest one of its kind in the country and includes sections on optics and sound, cable, instruments, power, battery, and insulation.

The activities of the optics and sound section cover investigations of intercommunication equipment, photometric measurements of illuminants, electrical and underwater, including searchlights and signalling equipment.

The cable section is concerned with the characteristics of electric conductor insulation, sealing cable ends, current carrying capacities of electrical conductors, and the physical characteristics of conductors to meet shipboard requirements, including the subjects of electrical and mechanical protection, with special attention given to the characteristics of rubber substitutes.

The instrument section investigates the characteristics of electrical instruments for portable and switchboard use, miscellaneous electrical instruments, and special applications.

The power section activities include investigation of the characteristics of conductors, resistors, and connections, infra-red radiation for heating, circuit breakers, contactors and relays, switches, transformers, and submersible types of equipment.

The battery section undertakes investigations of all elements of acid and alkaline cells and of the characteristics of their component parts. Extensive studies of the electrical characteristics have led to marked improvements in operation.

The activities of the electrical insulation section cover investigations and tests of solid and laminated synthetic materials, in molded, sheet, and tape forms, varnished cloth and varnishes, asbestos coverings, magnet wire coverings, glass fiber, treated papers, and synthetic cloths.

The work of the navigational division covers investigations and tests of gyro compasses and associated equipment, their repairs, and shock tests on mountings. Research and development are conducted on various forms of navigational equipment. This laboratory has the largest battery of Scorsby machines in the country. These machines put the navigational equipment through the rolling and pitching motions of a ship in a sea way.

The metallurgical division undertakes all phases of metallurgical investigations and tests of metals and alloys used in the fabrication of equipment, instruments, and ships' structures.

The mechanical division investigates and tests miscellaneous portable and stationary tools and operating equipment, linings for compartments, fire fighting equipment and materials, deck coverings, lumber and plywoods, and mechanical mechanisms for operating equipment. The development of materials includes tensile and tensile impact testing of structural members and materials and the effects of welding. Shock testing facilities determine the effects of shock upon ships' equipment and instruments. Facilities exist for the investigation of general airflow problems which occur in the design of ventilating systems.

The chemical division performs routine chemical services for the other divisions.

In addition to the special technical developmental activities, the material laboratory, Navy Yard, New York, completes hundreds of type and brand approval tests and thousands of routine inspection tests of material submitted under contract. Because of its geographical location, this laboratory is called upon to meet the demands for prompt and effective investigations and tests.

INDUSTRIAL TEST LABORATORY, NAVY YARD, PHILADELPHIA, PENNSYLVANIA

As in the case of other Navy Yard laboratories, the duty of the industrial test laboratory at the Navy Yard, Philadelphia, is to perform work to assist the shops and field in the solution of various engineering, chemical, and testing problems. However, this laboratory, like the material laboratory, Navy Yard, New York, has the additional functions of performing research, development, and testing work for the procurement of naval materials, especially in the metallurgical, textile, and chemical fields.

Testing work includes alloys of aluminum, copper, and magnesium, steel, textiles, paint, rubber, and miscellaneous chemical materials. The development work covers the examination of new products as regards suitability for naval use, the preparation of test methods for new specifications, and the testing of materials for approval. Recent developments have been made in high tensile steels, welding electrodes, tool steels, fire resistant paints, protective coatings, deck coverings, fire resistant cements, synthetic detergents, mold resistant materials, rubber substitutes, buoyant materials, wood preservatives, fire resistant textiles, synthetic rubberized fabrics, fire resistant life jackets, substitutes for silk powder bags, fire resistant linoleum, synthetic insecticides, plastics, and other materials. In general, this work has been directed along lines which will conserve critical materials, improve quality of naval purchases, and standardize materials and testing methods.

This laboratory is the Navy's principal resource for research into protective coatings other than those designed for submergence in sea water. These research investigations include the problems of surface preparation, methods of pickling steel, priming coats, exterior and interior paints, camouflage paints, and coatings for special services such as the linings of gasoline tanks. The Yard's recommendations in these respects have been instrumental in notable advances in protective coatings.

Although the development of the results of research, rather than the pure research itself, is the major function of this laboratory, research must often be undertaken when adequate data are not available from industry or naval research laboratories. Such research is usually of a nature which will be of value in the development or testing program. A major research problem is under way in connection with new methods and equipment for quantitative spectrographic analysis. This research has increased analytical accuracy, reduced time and man power, and increased test completion rate enormously. Such work is not only utilized by this laboratory but, when reported to the Bureau of Ships, is published and promulgated for the benefit of other government laboratories and for industry. Other instrument research includes metal crystal studies by means of x-ray diffraction inspection, standardization of camouflage colors, light filters, and the establishment of colorimetric standards and test methods with the recording spectrophotometer.

Research work is often done when the specific need arises for an item which has not been industrially produced in quality suitable for naval use. As a result, many articles have been formulated by the laboratory's research staff, tested, and found superior to current commercial offerings and specifications have been prepared for their procurement.

THE MATERIAL LABORATORY, NAVY YARD, BOSTON, MASSACHUSETTS

This laboratory is concerned with the inspection of materials and equipment, including analyses, testing, and examination of inspection samples submitted by inspection offices in this area. In addition, it specializes in laboratory examination of cordage manufactured by the rope walk operating in the Boston Navy Yard. Its activities also include special metallurgical problems, with particular emphasis on those concerned with the manufacture of dielock anchor chains.

EXPERIMENTAL DIVING UNIT, NAVY YARD, WASHINGTON, D. C.

This is the principal naval underwater testing unit and is concerned with all matters related to naval diving and submarine salvage operations. It investigates and tests related equipment including dresses, compressors, electrical and mechanical buoys, foul weather clothing, and special equipment. In collaboration with the Bureau of Medicine and Surgery and the Bureau of Aeronautics, the diving unit conducts research into the physiological aspects of high altitude flying and deep-sea diving.

Tests are conducted on underwater welding and cutting equipment for the repair and salvage of vessels. The results of these tests are used as a basis for purchase specifications. Much of this work is conducted in connection with research and development of similar equipment now under way at the Engineering Experiment Station.

PAINT LABORATORY, NORFOLK NAVY YARD, PORTSMOUTH, VIRGINIA

This laboratory assists the paint factory in the Norfolk Navy Yard in the solution of various production problems and performs research, development, and testing work incident to the manufacture and use of paints and other protective coating materials.

Its activities include tests and examination of representative samples of materials and completed products so that satisfactory quality control may be maintained on the output of the paint factory. It conducts research, development, and testing of new and improved products in the field of protective coatings, including the operation of an exposure station for panel testing at Yorktown, Virginia. It supervises the application of experimental products on ships in service tests.

CHEMICAL LABORATORY, NORFOLK NAVY YARD, PORTSMOUTH, VIRGINIA

This laboratory is concerned primarily with examination and tests of inspection samples and serves as a control for Navy Yard facilities. It specializes in the examination of inspection samples of paint, raw materials, and finished products for naval use in eastern United States.

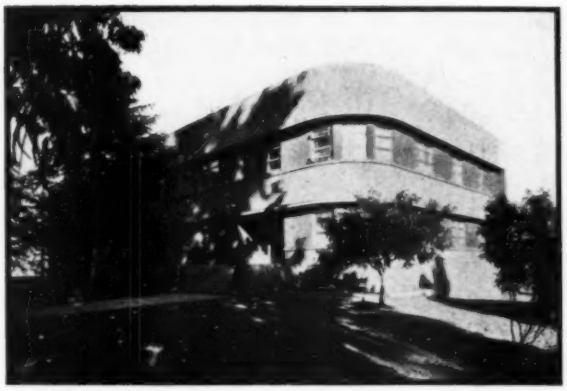


FIG. 2. Industrial laboratory, Mare Island, California.

METALLURGICAL LABORATORY, NORFOLK NAVY YARD, PORTSMOUTH, VIRGINIA

This laboratory serves as a control for the operation of the large foundries in the Yard. It supervises radiographic and other inspection tests of metals and other materials, including welding electrodes. It investigates heat treatments, casting and forging procedures, and new manufacturing processes for newly developed alloys for special applications.

PAINT LABORATORY, NAVY YARD, MARE ISLAND, CALIFORNIA

This laboratory serves in a manner similar to that of the paint laboratory at Norfolk, Virginia, but due to its geographical situation this laboratory has comparatively wide latitude in the initiation and prosecution of research, development, and testing of shipboard coatings, especially those for ship-bottom application. It supervises the operation of panel exposure barges where these ship-bottom coatings are tested for their efficacy in resisting fouling growths and barnacle attachments.

RUBBER LABORATORY, NAVY YARD, MARE ISLAND, CALIFORNIA

The function of the rubber laboratory originally was to instruct the personnel of the rubber mill under the production department in the production of various types of rubber equipment in order to maintain the necessary high quality of special Navy products. In order to determine the most suitable rubber compounds, it became

desirable to compare small batches in lieu of making experimental batches in the large rubber mill equipment. Utility of this procedure became of more importance as the technique became more complicated and as the development of synthetic rubber, alternate rubber materials, and rubber substitutes became of importance. In view of the complexity, the rubber industry was frequently unwilling to agree to modifications in Navy Department specifications. By utilizing the rubber laboratory as a proving ground, there has resulted a greatly superior production and the Bureau has been able to show the rubber manufacturers practical methods of producing desired materials.

INDUSTRIAL LABORATORY, NAVY YARD, MARE ISLAND, CALIFORNIA

This is one of the principal testing laboratories for naval material on the Pacific Coast. Its metallurgical section conducts examinations of metal at a high magnification and performs heat treatment controls. It makes local recommendations for substitutions of steels and alloys. The materials test group is concerned with weathering and other tests of materials, shipboard test equipment for ventilation, and other electrical problems. The sound and vibration section conducts investigations and research on shipboard, with special reference to rotating equipment. The chemical section analyzes samples of all ferrous and non-ferrous metals. The non-metals section is concerned with investigations of the characteristics of paint and petroleum. The petroleum unit tests lubricating oils and fuels. The miscellaneous and special problems group handles problems on miscellaneous materials and is concerned with corrosion problems.

Spectrographic and electrical characteristics of insulated cables comprise another activity. Technical advisors act as consultants for those concerned in naval repair and manufacturing work in the region.

INDUSTRIAL LABORATORY, NAVY YARD, PUGET SOUND, BREMERTON, WASHINGTON

This is a general laboratory concerned with the inspection of materials and equipment, including chemical analyses, physical testing, and metallurgical examination of inspection samples required by the yards, shops, and related activities of the Pacific Northwest area.

Official U. S. Navy Photograph

At the Navy Ordnance Proving Ground at Dahlgren, Virginia, every gun installed on ships is proof-fired and every type of armor-plate and explosive is thoroughly tested before being placed in the service. In this photograph, the armor-plate target by mirroring the glare thrown by the blast of the 5-inch gun, throws up a beacon of light as it repels the shell, thus checking both cannon and armor-plate in one operation.

Research in the Bureau of Ordnance

BY CAPTAIN W. M. MOSES, U.S.N.
Director, Research and Development Division

CAPTAIN
WILLIAM M. MOSES

THE U. S. Navy charges its Bureau of Ordnance, in the official language of the Navy Regulations, with "the design, manufacture, procurement, maintenance, issue, and efficiency of all offensive and defensive arms and armament (including armor, torpedoes, mines, depth charges, pyrotechnics, bombs, ammunition, war explosives, war chemicals, defensive nets, booms, and buoys, plus anchors, moorings, and appliances therefor, except fixtures on shore for securing the ends of nets and booms) and, except as specifically assigned to other cognizance, optical and other devices and material for the control of guns, torpedoes, and bombs." Thus, everything that the Navy uses to wreak damage on the enemy or, with some few exceptions, to defend itself against the weapons of the enemy, lies within the field of naval ordnance.

Research in ordnance is, of course, primarily concerned with the original design of weapons and ordnance material, but its contribution to the effectiveness of ordnance in action does not stop there—research is equally necessary for maintenance and efficiency. Few, indeed, are the items that are not subject to continued research in the laboratories, in the manufacturing plants, or in actual service, always with the goal of providing better weapons in ample quantities in sufficient time.

Research, therefore, must be far in the van of ordnance developments, cognizant of new needs long before those needs must be met in the test of battle action, aware of every useful resource and all latent or unexploited knowledge that might conceivably contribute to the solution of new ordnance problems. Research activity, alert to the ups and downs of ordnance performance under battle conditions, must follow every item of ordnance from the drafting board to its actual contact with the enemy. That research, moreover, must not be academic, interested in the defense of a design or a theory, but practical and agressive, eager to find flaws in its own work, avid to correct, improve, and develop, and keen to apply new principles and ideas to good effect.

Research activity in the Navy Bureau of Ordnance is organized and directed by one of the Bureau's six divisions. The Bureau is administered through these divisions, set up along functional lines, based on the principles of decentralization of responsibility and delegation of authority. The Chief of the Bureau, now Rear Admiral George F. Hussey, Jr., heads the entire organization, operating through the directors of the divisions, which are designated the Planning and Progress, Administrative, Finance, Research and Development, Production, and Fleet Maintenance divisions. The names, in general, describe the duties of each division.

The design and development of all naval ordnance material is the responsibility of the Research and Development Division of the Bureau of Ordnance. This division conducts a good deal of original research, particularly with regard to changes and modifications of existing equipment, and supervises and coordinates the research work done by several of the ordnance stations (some of which are described elsewhere in this issue) and by the

REAR ADMIRAL
GEORGE F. HUSSEY, JR.
Chief, Bureau of Ordnance

many civilian activities currently engaged in ordnance research.

The magnitude of the research task laid upon this division at present extends beyond the boundaries of the naval establishment and employs the talents and facilities of science and industry. The Office of Scientific Research and Development, organized to meet the research problems created by war, brings the laboratories and research staffs of huge industrial organizations, of scientific bodies, of universities and colleges, into a great pool of knowledge, where the needs of defense research can be met with the speed and efficiency necessitated by the scope of the emergency. Working with and through this office, the Research and Development Division has drawn upon the facilities of the manufacturing, the educational, and the purely scientific institutions of the country that have made many contributions to naval ordnance.

Considerations of security forbid any attempt to tell the full and complete story of research in the field of naval ordnance. Much talk of "secret weapons" has filled the air since the war began, and much of it has been psychological. Secret weapons, however, must be capable of more than scaring the enemy. Like any other secret, too, they lose much of their potency once the secret is out. The history of ordnance is the history of secret weapons, for which ordnance research quickly develops a secret antidote, while both secrets rapidly become part of the standard armament of all military establishments. The offensive spear was met by the shield. When the shield was pierced by bullets from a new secret weapon, armor was the answer. In naval ordnance the race has been between methods of sinking ships and methods of keeping them afloat, methods of improving and increasing their firepower, and methods of wiping that firepower from the surface of the seas. It is a never-ending struggle between offense and defense.

The functions of ordnance research in developing new weapons to sink the ships and neutralize the guns of the enemy, and to outwit his efforts and devices to eradicate or reduce our own floating firepower have not been neglected by the U. S. Navy in this war. The development of aviation as a major factor in naval, amphibious, and global warfare has demanded new offensive and defensive weapons which have included improved versions of conventional ordnance devices and radical departures from the weapons used in past war.

Both the Germans and the Japanese, in this war, have suffered from the efficient operation of devices which are new to warfare, or which are new developments of old principles. What these devices are, how they function, how they were developed, and how effectively they take toll of the foe may never be told. All that can be said is that such devices have been sent into action and have destroyed enemy forces in all the spheres of warfare where they have been used. To say more than that, at any time, would be to cancel the advantages earned by ordnance research in the development of weapons capable of delivering a surprise to the enemy. In our own experience, we know that the bare knowledge that the Germans or Japs have developed a certain kind of new device, or improved the performance of an old weapon, has been sufficient spur to produce a similar or a better one for ourselves.

Whether the problem is one of developing a new device to meet a new condition of modern warfare, of redesigning existing weapons to meet changing conditions, of finding a defensive device to counteract enemy activity, or merely of maintaining the present efficiency of traditional weapons, the Research and Development Division of the Bureau of Ordnance is responsible. That responsibility includes the preparation and issue of drawings and specifications required for production, and the preparation and issue of instruction pamphlets and other literature necessary to insure proper and efficient operation and maintenance in a state of instant readiness for action.

In the performance of its functions, the division is divided into six sections, organized along production classification lines. Two assistants, one for administration and one for aviation, aid the Division Director. The assistant for aviation is an active naval aviator who has specialized in aviation ordnance.

Key officers, those who formulate policies and hold major responsibilities in the Bureau of Ordnance, are line officers of the regular Navy. This is especially true of the Research and Development Division. These men are seagoing

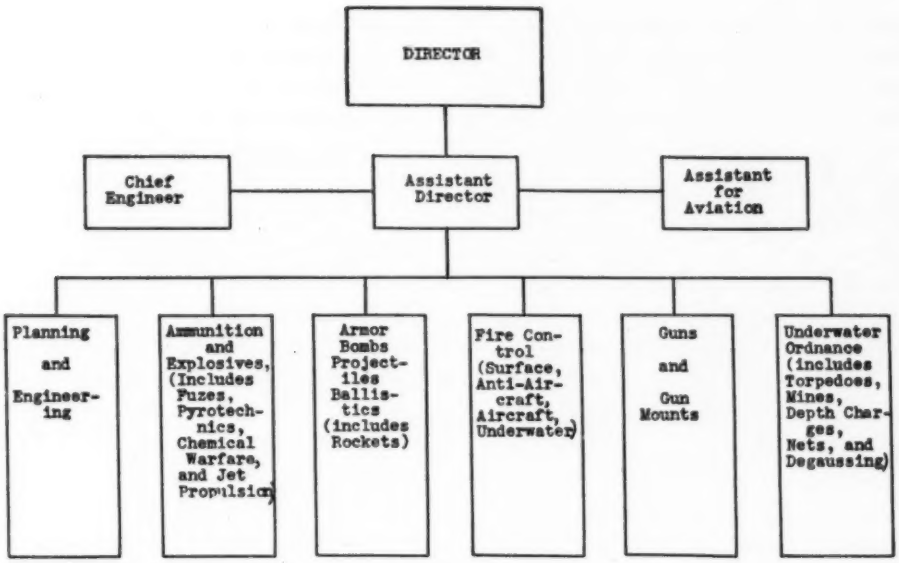

DIRECTOR
Chief Engineer
Assistant Director
Assistant for Aviation
Planning and Engineering
Ammunition and Explosives, (Includes Fuzes, Pyrotechnics, Chemical Warfare, and Jet Propulsion)
Armor Bombs Projectiles Ballistics (includes Rockets)
Fire Control (Surface, Anti-Aircraft, Aircraft, Underwater)
Guns and Gun Mounts
Underwater Ordnance (includes Torpedoes, Mines, Depth Charges, Nets, and Degaussing)

FIG. 1. Chart showing the organization of the Research and Development Division of the Bureau of Ordnance.

officers who alternate duty in the fleet—aboard ship or attached to aircraft units—with service ashore. They are aware of the requirements and limitations of needed equipment and, from close familiarity with the fighting problem, are in a position to recognize what items are needed and with what priority. Most of them have spent a number of years at universities, private plants, and laboratories as post-graduate students on ordnance matters subsequent to graduation from the Naval Academy, followed by ordnance assignments both afloat and ashore. The Division's work is carried out under the direction of these men together with a number of reserve officers commissioned from civilian life who have extensive technical experience and background in universities, private laboratories, and research organizations.

At the present time nineteen of the approximately two hundred officers on duty in the Research and Development Division are regular naval officers on the active list. Fourteen of them have had post-graduate courses and have specialized in ordnance for the greater part of their careers. All have come to the Bureau of Ordnance direct from the fleet. The Division Director was Fleet Gunnery Officer of the Atlantic fleet; the administrative assistant was gunnery officer of a heavy cruiser; the aviation assistant was in command of an air group on one of the largest carriers. Of the others, one commanded a submarine; three were destroyer skippers; one commanded a minelayer; one commanded a squadron of scouting planes; another was a member of a scouting plane squadron; one was on the staff of the Commander-in-Chief, Pacific fleet; one came direct from a gunnery training ship, and the others were either gunnery or assistant gunnery officers on battleships, cruisers, or carriers. They are a representative lot, well qualified to serve in their present assignments. Five of them have been decorated; one of them four times, another twice.

The sections of the Research and Development Division are designated: Planning and Engineering; Ammunition; Armor, Bombs, and Projectiles; Fire Control; Guns and Mounts; and Underwater Ordnance. These explicitly-named sections are responsible for every type of naval ordnance. They initiate and prosecute all design, development, experimental, and research efforts affecting the types of ordnance which are their special care. Through their activities, the division supervises and coordinates all design, development, and experimental research done for the bureau by outside agencies, as well as that done by its own specialists, both naval and civilian.

Projects are conceived in a number of ways. They may originate in private industry, university laboratories, or research organizations, either at the suggestion of the Army or Navy Departments, or completely from within the former. Projects, or ideas for them, may be suggested from the fleet, consequent to problems based on new tactical developments, or learned from actual combat. They may also originate as a result of the discovered effectiveness of new enemy ordnance, or at the suggestion of members of allied military liaison groups working under the combined chiefs of staff, which have made possible a relatively free interchange of information on such matters between the United Nations' ordnance groups. Most projects for new or improved weapons and equipment originate, however, in the bureau's Research and Development Division.

Regardless of the origin of a particular problem, the research work on it and the connected development are handled by the Bureau of Ordnance through its Research and Development Division. General or rigid specifications are set up, depending upon the problem at hand, with aforehand knowledge of shipboard or plane requirements and limitations, and with the basic consideration of what the general purpose of the weapon must be. The research may be handled through the Office of Scientific Research and Development, or its subsidiary, the National Defense Research Committee and affiliated organizations, or through one of the private research establishments, a university, or an institute. Representatives of the bureau work very closely with the organization handling the project and supervise the work until the item is ready to be turned over to the Production Division, or is discarded. A great deal of the experimenting and practically all of the testing are done under naval supervision at the various ordnance stations, such as the Naval Proving Ground, Dahlgren, the Naval Gun Factory, the Naval Mine Warfare Test Station, and others. Only after exhaustive tests under simulated prospective combat conditions are the items considered ready for production for the fleet. Actual service tests are prescribed wherever possible. Frequently the solution of one project yields conclusions which have bearing on other projects. These are correlated through the division.

The Planning and Engineering Section coordinates the activities of the other sections based on over-all programs set up by the division director. The work of this section covers the activities of the chief engineer of the bureau, the drafting room (which requires the full-, and often overtime, work of approximately 350 drafting and engineering personnel), the preparation of reports, patent investigation, and matters of administration affecting the personnel assigned to the division.

The Ammunition Section handles research and development projects of all types of fuzes, propellants, high explosives, chemical warfare agents, pyrotechnics, rocket propulsion, and the multitudinous small units embraced under the general term, "ammunition details."

Fuzes, detonators, and similar devices on which depends the proper operation of projectiles, mines, depth charges, bombs, and scores of other items of ammunition, explosives, and ordnance devices, represent a field in which research and experiment accomplish constant advances. The development of timing and detonating devices of unbelievable delicacy, accuracy, and effectiveness is an important phase of ordnance research. Powders of improved sensitivity, power, and explosive quality, with special characteristics to serve special purposes, have been evolved through intensive studies. High explosives of varied types, chemicals for smoke screens and for gas warfare, antigas equipment, and the materials from which these categories of naval ordnance are developed, constantly undergo intensive study to reveal possibilities for improvement in composition, handling, and storage. Ammunition containers and cases, designed not only for the preservation of their contents, but for the maximum economy of space and efficiency in stowage in shipment, are not the least of the responsibilities of the ammunition section.

The Armor, Bomb, and Projectile Section covers the problems connected with all types of bombs and projectiles, ballistic and armor studies, including tests and specifications. Aerial bombardments have made the manufacture of bombs a major item in the ordnance industry; hence, the development of bombs ranging from a few pounds

to two or more tons, specially designed to do a specific job of destruction, has become a major task of ordnance research. Armor-piercing bombs, demolition bombs, anti-personnel bombs, fragmentation bombs, depth bombs—those are just a few of the made-to-order destruction bearers which fall from the bomb bays of naval planes. Projectiles ranging in size from the tiny shells fired at the rate of 600 or more per minute from a 0.50-caliber machine gun to the more than 2000-pound projectile that flies from the 16-inch gun of a battleship are designed for maximum performance through the combined efforts of this section, in collaboration with the ammunition and gun and mount sections. Armor-piercing shells, high capacity projectiles, anti-aircraft ammunition, and other projectiles designed for special purposes are under continuing study.

The Fire Control Section is concerned with the improvement of current equipment or the development of new devices to control the ordnance of the fleet. Devices developed under the cognizance of this section direct the fire of the main battery guns, the underwater ordnance, and the anti-aircraft armament of our ships, so that they can be trained quickly and accurately upon the swift-moving targets of this war. Miracles of precision in firing our guns at distant targets and at targets sweeping across the sky have been made possible by the control equipment furnished for Navy guns. All the problems connected with the various types of directors, optics, controls, and partial or complete fire control systems, receive the attention of the Fire Control Section. The smallest details of the intricate systems for assuring quick and accurate use of Navy weapons are thoroughly worked out by this section.

Official U. S. Navy Photograph

FIG. 2. 20-mm guns on a "flat-top."

Official U. S. Navy Photograph

FIG. 3. 40-mm guns in action.

The Gun and Mount Section handles studies and projects affecting guns of all types, ranging from the 16-inch rifles that make up the main battery of a battleship, down through the smaller caliber anti-aircraft guns aboard ships, and the machine guns and automatic cannon carried by airplanes. This section works also on developmental problems connected with gun mounts, power drives, turrets, elevation and train controls, bomb racks, hoists, and the innumerable other related items of equipment which help to produce a weapon spitting fire against the enemy. The armament of aircraft receives special study in this section, to meet the problem of mounting guns, rockets, and bombs of increasing size and power on carrier-based planes and patrol aircraft. The development of higher rates of fire, the extension of the effective range of all naval guns, and similar problems fall within the scope of this section.

The development of underwater ordnance and its research is handled by the Underwater Ordnance Section. This section works on projects connected with various types of torpedoes, airborne, surface-ship, and submarine, and the tubes and racks from which they are launched. Mines, both offensive and defensive, represent one of the

Official U. S. Navy Photograph

FIG. 4. One of the Navy's motor torpedo boats—torpedoes, depth charges, and machine guns add to their sting.

little-discussed, but highly important fields of research for this section. Depth charges, the "ash cans" carried by anti-submarine fighters, from PT boats to blimps, the racks in which they are carried aboard ship, and the projectors which toss them into the sea where an enemy sub may lurk—these, too, are underwater ordnance, to be developed, improved, and made more efficient by the studies of the underwater ordnance men. Net and boom defenses, degaussing, and deperming are other fields in which this section operates. Nets to protect our advance base harbors and our vital ports at home from submarine and torpedo-boat attacks are improved to keep pace with the technique of sneak attacks. Methods for controlling the natural magnetism of metal ships to protect them from the enemies' magnetic weapons are prepared and tested. Studies of counter-measures against enemy devices are made by a corps of specially trained officers.

This wide field of operations covering all the research activities directed and drawn upon by the Bureau of Ordnance in the interest of providing the U. S. Navy with the most effective tools of offense and counter-offense, is coordinated with the work being prosecuted in the industries which, in time of war, become makers of ordnance, instead of their usual peacetime commercial products. The engineers whose peacetime interests are directed toward improved designs of motor cars, the streamlining of pleasure craft or household items, and the functional designing of furniture and containers can shift their knowledge and techniques into the field of ordnance and do so with great success.

One of the outstanding developments of naval ordnance in this war is the tremendously enhanced ability of American ships to repel air attacks. Early in the war many prophets predicted the early demise of naval surface ships, but far from having succumbed, these ships have not only survived, but greatly multiplied in number, and several new types have been created.

Research, directed by the Bureau of Ordnance in its determined effort to explore every existing resource which may contribute to the effectiveness of naval ordnance in action, reaches into nearly every phase of American life. This is particularly true in wartime, when all facilities of the country are put at the disposal of the military services. The collaboration which is now in effect between the Army and the Navy, in the working out of ordnance problems which can be solved jointly by the two services, in the exchange of information, research, and developments, and in the interchangeable use of ordnance equipment where such exchange of equipment is possible, is present also in a working partnership between ordnance, as a military activity, and science and industry, as social and economic institutions. The very real, all-out cooperation and assistance of both industry and science, combined with the enthusiasm and interest displayed by the individual men and women engaged in the actual development projects, are matters of pride and gratification to all who know the story of research behind United States naval ordnance.

Research Activities of the Naval Ordnance Laboratory

BY CAPTAIN W. G. SCHINDLER, U.S.N.
Officer-in-Charge, Naval Ordnance Laboratory

***Author's Note:** This article might better have been written after the war is won. The work being done by the Naval Ordnance Laboratory furnishes some extremely interesting examples of the application of theoretical and experimental physics to the practical business of war. Unfortunately, details of this work cannot yet be revealed. It is possible, however, to give general pictures of some of the problems in which the laboratory is engaged and their relation to naval warfare. That is the intent of this article.*

THE Naval Ordnance Laboratory, located in the Washington Navy Yard, is an organization charged by the Bureau of Ordnance with the design and development of naval weapons and associated ordnance material. This includes mines, depth charges, projectile fuzes, bomb fuzes, pyrotechnics, torpedo mechanisms, and various items of equipment to protect our own ships against enemy weapons. It may not seem likely that an organization with such purposes would engage in any very considerable amount of scientific research. Yet in 1940 the laboratory undertook one of the most monumental research programs of the war.

The program was initiated because in November, 1939 Germany introduced a deadly new naval weapon—the magnetic mine. Perhaps a brief sketch of the development of mine warfare up to that time will best explain why the magnetic mine was such a radical, and potentially dangerous, development.

The mines of World War I were, with unimportant exceptions, buoyant spheres or cylinders loaded with explosive and moored to anchors by long cables. Some types fired when bumped by a ship; other types fired when ships struck antennae on the mines; still others were fired by shore controls at any desired time. They were generally laid from surface ships, and therefore were essentially defensive weapons—that is, used to keep the enemy out of one's own waters or to deny him the use of strategic areas—since it was rarely possible for a minelayer to penetrate near enough to any enemy coast to lay mines in his shipping lanes.

A prime example of the use of mines in World War I was the enormous barrage of over 70,000 laid from the Orkneys to the southern coast of Norway to seal the German surface and submarine fleet within the North Sea. The success of this barrage, incidentally, was one of the chief reasons the Bureau of Ordnance established the Naval Ordnance Laboratory and charged it with the development of new mine designs.

CAPTAIN
W. G. SCHINDLER

Such mines had important tactical uses—in fact, more ships were sunk by mines in World War I than by gun fire. However, their defensive nature limited their usefulness as naval weapons.

It was evident that these limits had been virtually removed when it became known what caused the explosions that sank British ships near the coast of England, and in her very harbors, in the early months of this war. A successful recovery and courageous disassembly by the British of an unexploded mine shortly after the first ones were laid revealed that the Germans had a mine which lay on the bottom—known, therefore, as a "ground" mine—and fired when a ship came sufficiently near to it. The firing mechanism was a magnetic needle which moved under the influence of the magnetic field of a passing ship and thereby closed a firing switch.

These first mines were planted by aircraft, a new method. It was obvious that they could also be built in forms which would allow them to be planted from submarine tubes. Thus, the Germans had produced mines which could be laid

Official U. S. Navy Photograph

FIG. 1. Laboratory buildings. The original Naval Ordnance Laboratory building, constructed in 1918, consists of the first three sections of the structure in the foreground. New buildings are the small addition in the right background, the separate building behind it, and the large structure in the left background.

in British harbors and shipping lanes, and, by doing so, had made offensive mining possible.

The value of offensive mining is not usually appreciated. A plane with a load of mines, or a submarine with mines in its tubes, under some conditions can be more useful in the over-all conduct of a war than the same plane with bombs in its racks or the same submarine carrying torpedoes. If a bomb or torpedo misses, then the target ship knows it has no more to fear from that particular missile. But, since mines are usually laid in groups, or fields, the explosion of one is almost a guarantee that others are in the vicinity. Therefore, a ship which has just escaped a mine explosion must still presume itself in danger. Unless the enemy is willing to take the desperate gamble of sailing through an area known to be mined, he must either avoid the area completely, or, if it is a harbor or shipping lane too valuable to be thus abandoned, he must explode or otherwise render harmless the whole field. The latter procedure, called sweeping, is slow and dangerous; the sweeper can never be sure of complete success; and, finally, specialized equipment—which may not be immediately available—is needed. In this war, valuable harbors have been completely tied up for weeks at a time by a single mining operation. Further, since the use of aircraft and submarines allows mines to be planted almost anywhere, a nation against which mines are used is forced to maintain a large fleet of sweeping vessels scattered throughout her strategic waters, thus tying up both men and ships. Obviously offensive mining can be a highly useful tactical measure.

The worst feature of the new weapon, as far as the British were concerned, was that the usual sweeping procedures against moored mines—cutting them loose from their cables and destroying them by gunfire when they came to the surface—were useless against mines which lay on the bottom. Some entirely new method of sweeping or of protecting ships against mines had to be devised. Within six weeks of the time when the new mine was identified, the British had found workable methods of doing both.

The protective equipment devised by the British was called "degaussing" apparatus. It consisted essentially of a girdle of cables wound around a ship. When large electric currents, generated aboard the ship, were passed through these cables, the vessel became in effect a huge electromagnet. Its field might then be made so strong that it would explode mines too far away for them to cause damage, or its normal magnetic field might be neutralized so that the mines would not be fired.

This early degaussing equipment, while it reduced the number of ship casualties from magnetic mines, was far from perfect. It was soon recognized that the best possible protection would be degaussing equipment which reduced the underwater magnetic field of a ship to zero intensity. To produce such equipment, precise and extensive knowledge was required of ships' magnetic fields at various depths and—since this is a global war—at various geomagnetic latitudes. This information did not exist in England or in America, because the subject had not been extensively studied in these countries before the war.

The Bureau of Ordnance was quick to recognize the threat presented by magnetic mines in the hands of a potential enemy, and the tremendous possibilities of their use by our Navy. Accordingly, the Naval Ordnance Laboratory was authorized early in 1940 to make a complete study of the fields of ships, to develop methods

of neutralizing ships' fields, and to develop mines utilizing these fields. The general principle of a magnetic mine was not new to the laboratory, since it had designed and experimented with two models of magnetic mine-firing mechanisms near the end of World War I. However, these never got beyond the experimental stage. Their further development was prevented during the somnolent peace years, when Navy funds were so restricted that the laboratory's scientific staff was at one time reduced to one physicist working on mines and mine design, and one engineer working on projectile fuzes and pyrotechnics.

When the laboratory was given its urgent research projects, the scientific staff consisted of fewer than 20 physicists and engineers, working under the technical direction of Dr. R. C. Duncan and under the general supervision of Commander J. B. Glennon, U.S.N. (Ret.), the Officer-in-Charge. Since these few men, able as they were, could not hope to do more than a small fraction of the work involved, the laboratory entered a period of tremendous expansion.

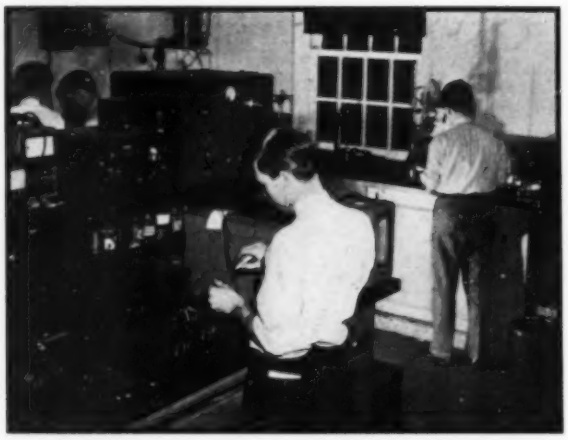
Experts were called in from all over the country. Mr. E. A. Johnson (now Lieutenant Commander, U.S.N.R., on active duty in the Pacific) came from the Department of Terrestrial Magnetism of the Carnegie Institution of Washington to head the group studying degaussing and the measurement of ships' magnetic fields. Dr. R. D. Bennett, Director of Graduate Research in Electrical Engineering at the Massachusetts Institute of Technology, Lieutenant Commander, U.S.N.R., accepted a call to active duty in July, 1940, and, because of his wide acquaintance with the scientists of America, was assigned the task of recruiting the men best qualified to carry on the laboratory's work. Commander Bennett soon recruited physicists and engineers from the nation's foremost universities and industrial laboratories—a task made somewhat easier by the fact that other government activities had not yet started expansion programs. Gratitude is due these scientists for their willingness to interrupt their careers to come to Washington, often at considerable personal sacrifice, and also to their employers for the generosity with which they granted leaves of absence. These men formed the nucleus of a staff which was swiftly expanded to keep step with the ever-increasing scope of the research programs.

Official U. S. Navy Photograph

FIG. 2. Testing tank. Underwater tests of new weapons are conducted in the large tank in the center of the photograph. At the right is the original Naval Ordnance Laboratory building, at the left a new building in which many of the laboratory's activities are housed.

(It would be a long overdue, and well-merited, gesture of recognition to list here every scientist and engineer who has come to the laboratory's assistance during this war, that their fellows might know the men and women for whose unstinting service to their country the Navy is grateful. However, the list would contain too many names for the space available.)

The first task on which the laboratory concentrated was the study of ships' magnetic fields. Completion of at least a part of this was a prerequisite both to the design of adequate degaussing apparatus and to the design of mines using these fields. The major difficulty in this study was a compound of its wide scope, its virtually virgin status in this country, and the speed with which it had to be made.



Official U. S. Navy Photograph

FIG. 3. Ammunition experiments. A view of the part of the Naval Ordnance Laboratory where experimental ammunition is made and tested. Because of the hazards involved in this work, it is carried on in a separate building.

Practically all the instruments by which measurements were made and recorded had to be either made by modifying existing apparatus, or designed and built from scratch. One result of this effort has been to produce revolutionary techniques for rapid and accurate measurement of magnetic fields of the order of a few milligauss. While the need for new instruments is not an uncommon feature of research programs, the fact that geomagnetic effects vary with latitude, and that therefore the laboratory's measurements had to be made in widely separated areas, meant that an uncommonly large number of such instruments had to be procured and stations set up to use them. Their swift procurement was made possible only by the cooperation of the Navy Supply Corps and of many manufacturers of such equipment.

Laboratory engineers helped set up well-equipped measurement stations in far-flung locations in record time. The first of hundreds of thousands of magnetic measurements on thousands of ships—ranging from barges to battleships, from tugs to transports—began to pour into the laboratory.

These measurements gave the men working on degaussing a basis on which to start, but they were not in themselves enough to solve the problems. The investigation soon began to involve the use of complex mathematical theory. To help with this, some of the country's most capable mathematical physicists came to the laboratory's aid. However, not all the work was on this level. A great deal of it was arithmetical computation, involving plain hard work with pencils, paper, and computing machines.

One of the most tedious of the tasks was extrapolating data taken at one depth to make it applicable to other depths, thus making it unnecessary to tie up urgently needed ships, men, and measuring apparatus for more than a relatively few measurements. This extrapolation, it was felt, could be done much more rapidly and accurately by a machine. A general description of what was wanted, and specific ideas on how it might be made, were furnished to the National Defense Research Council. In only 16 weeks, an extrapolator was made up and installed. With this machine two men can easily make a complete study of the field of a large ship in one day. The same task would take a computer, using standard computing machines, a month or more of hard work.

The design of degaussing equipment went forward rapidly as soon as sufficient data had been secured and analyzed. The British had furnished the Navy a simple degaussing formula in January, 1940; the laboratory designed our original degaussing coils with its aid shortly thereafter, then proceeded to make almost day-to-day refinements as the results of the studies

Official U. S. Navy Photograph

FIG. 4. Equipment. Research facilities of the Naval Ordnance Laboratory include such elaborate equipment as is shown here. While the finest commercial products are available, for many uses special instruments must be designed and built.

became available. By the middle of 1942, the problem of creating a nearly perfect defense against the magnetic mine had been solved. Exactly how much a ship's field can be reduced by the methods finally worked out is, of course, information the enemy would like very much to have. However, one example of the perfection degaussing techniques have reached can be given. It is now possible while a ship is still only on paper to design degaussing apparatus which will need only minor adjustments after the ship has been completed. When one considers the magnetic complexity of a steel battleship, it is apparent that the theory of degaussing has reached a high order of development.

While at first the bulk of the laboratory's scientific personnel was engaged on the immediate problem of studying magnetic fields, some went to work at once to create new magnetic mines for the Navy. The number of these latter workers increased rapidly as time went on. Several types of new mines were developed beyond the experimental stage in the few short months before our own country was at war.

The design of offensive weapons has for some time occupied most of the personnel and facilities of the laboratory. The present status of development of our magnetic mines cannot be discussed for reasons of security. It betrays no secret, however, to say that they are deadly and efficient, as enemy navies have already learned from bitter experience.

Official U. S. Navy Photograph

FIG. 6. Air gun used in Naval Ordnance Laboratory tests. The long tube is made from the liner of a 14-inch gun barrel. Small mechanisms are shot through it by compressed air to test their ability to stand severe shocks.

Official U. S. Navy Photograph

FIG. 5. Magnetic investigations at the Naval Ordnance Laboratory. The ship on the table is magnetically a scale model of a warship. It is being prepared for magnetic measurements under controlled external field conditions. Investigations of models like these have proved very helpful in establishing degaussing techniques.

The studies of underwater magnetic fields of ships represent the main bulk of work of a research nature done by the laboratory that can be mentioned. There now exist masses of valuable data, and volumes of equally valuable analyses of them, on subjects which were virtually unknown only four years ago. However, the magnitude of these programs has not prevented the laboratory from carrying on an increasing amount of research more limited in scope. The development and use of mines have posed many baffling problems in such subjects as air and underwater trajectories, the effects of water currents on moored buoyant bodies, the corrosive effects of sea water on various metals, the life of batteries under various conditions, the nature and effects of explosions and explosive waves, and many

Official U. S. Navy Photograph

FIG. 7. Underwater explosion test. A small charge has just been set off under water as part of the Naval Ordnance Laboratory's research program on the effects of explosions. The 40-foot boat in the foreground was thrown violently into the air immediately after this picture was taken.

others which cannot be mentioned; all have research men hard at work on them, securing useful results.

The laboratory has also undertaken the development of a number of items of ordnance equipment required, sometimes in small quantities, but often in an incredibly short time, for special missions. And there is the continuing task of solving maintenance problems for ordnance equipment already in service.

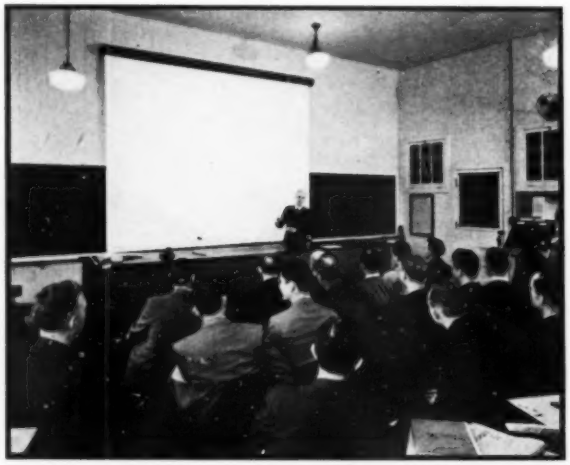
The nature of the laboratory's work has led to the development of many items of specialized equipment. Among these are: an impact tester, made from the liner of a gun barrel, through which mechanisms are shot by compressed air to test their ability to withstand severe shocks; vibrating machines capable of shaking extremely heavy bodies; controlled-temperature chambers in which the effects on mechanisms of the heat of the tropics and the cold of the stratosphere are tested; and many others. This equipment, designed to simulate service conditions as far as possible, makes it possible for the laboratory to be sure its many delicate mechanisms will stand up to the treatment received in the field.

It should not be supposed that mines and mining are the only activities of the laboratory which have gone swiftly forward. Extensive research and development work on depth charges and depth charge firing mechanisms has been carried on. Depth charges have come a long way from the "ash can" days when they were merely hydrostatically operated devices—looking much like ash cans—that exploded when they reached a set depth. Some types are now extremely complex in design and operation—and deadly to submarines.

The laboratory's work on torpedo mechanisms, pyrotechnics, and fuzes for projectiles and bombs, has produced notable increases in efficiency of these devices also. As an example of the precision work required on fuzes, some are made to give accurately a delay of as little as 10 milliseconds in exploding a bomb or shell after impact. Such precise timing must be built into fuzes rugged enough to penetrate heavy armor plate before exploding.

Perhaps the best way of stating the scope of the work of the laboratory is to say that whenever an enemy ship is destroyed by a naval mine, bomb, or shell, or whenever an enemy submarine is crushed by a naval depth charge, or whenever an enemy plane is shot down by naval anti-aircraft, then a laboratory product has done its work well.

One other laboratory project has not yet been mentioned: that is, the training of young naval officers who learn the intricacies of our mechanisms by working with the laboratory's physicists



Official U. S. Navy Photograph

FIG. 8. Instruction. Teaching naval officers and civilians the intricacies of mechanisms used in mine warfare is an important part of the Naval Ordnance Laboratory's work. The officers go to battle stations as mine experts; the civilians use their knowledge in producing more new weapons.

and engineers. These men have the run of the laboratory—an arrangement which has often proved as valuable to the laboratory's work as it has to them, since many a capable young scientist is in their ranks. When their training is complete, they go to battle stations all over the world to aid in putting new weapons into use against the enemy.

Some final facts about the laboratory's size may be of interest. In January of 1941, after expansion had started, the total technical staff of the laboratory numbered some 60 persons. By July of 1941 there were 300 staff members; by January, 1942, 500; and by July, 1942, 800—a level which was held fairly constant until recently. More than 1000 persons have participated in the work of the laboratory in this war, although the present complement has been somewhat reduced because the laboratory has supplied several hundred of its experts to field stations and to other sections of the Navy, some as civilians and some as officer specialists.

Those who know the problems that can be created by even the gradual growth of a laboratory will appreciate the vast amount of administrative work that was needed to keep this organization on an even keel during its tremendous expansion. The credit for this should be apportioned among three men—Dr. Duncan, the civilian head of the laboratory; Commander Bennett, recruiter and immediate director of much of the staff; and my predecessor as Officer-in-Charge, Captain Glennon. Under their direction, the laboratory has been a coordinated working unit which has helped substantially in giving the Navy new weapons for victory.

Research and Experimental Activities of the U. S. Naval Proving Ground

BY CAPTAIN DAVID I. HEDRICK, U.S.N.
Commanding Officer, U. S. Naval Proving Ground

The United States Naval Proving Ground, Dahlgren, Virginia, is an activity of the Bureau of Ordnance, Navy Department. Rear Admiral George F. Hussey, Jr., U. S. Navy, is Chief of the Bureau of Ordnance. Captain David I. Hedrick, U. S. Navy, is the Commanding Officer of the Naval Proving Ground. All tests and experimental work are conducted in the Ordnance Division of the Proving Ground under the supervision of Captain Festus F. Foster, U. S. Navy, Ordnance Officer. The work carried on in the Ordnance Division is apportioned among several departments, including an experimental department, each headed by an officer of the United States Navy.

I

THE United States Navy has maintained a shore station since 1872 to test the guns, projectiles, ammunition, armor, and other ordnance material sent to the fleet. The first naval proving ground was located on the Severn River near Annapolis, Maryland, then transferred to Indian Head, Maryland, in 1890, and to its present location at Dahlgren, Virginia, in 1918, each new location being chosen to accommodate the increasing range of the guns carried by modern battleships. The U. S. Naval Proving Ground, Dahlgren, Virginia, now has facilities for testing all guns and mounts, projectiles and powder, fuzes, bombs, bombsights, armor plate, and many miscellaneous devices used by the Navy. There are five major batteries facing the waterfront and a 90,000-yard range over water down the Potomac River, and a several-thousand acre reservation on which are located the batteries and attendant buildings, experimental laboratories, administration buildings, an airport, and a small village. There are now more than a thousand officers, enlisted men, and civilians directly engaged in testing and experimenting with naval guns, projectiles, and other ordnance material. A part of this personnel is engaged in research to make routine tests more effective and economical, to develop new special purpose tests, and to develop new and better weapons and armor.

The technical and research projects fall into two classes: namely, projects concerned with improving routine acceptance tests and devising new tests for production material bound for the fleet; and projects concerned not with production material, but with improvement of the weapons and armor itself.

CAPTAIN
D. I. HEDRICK

II

In connection with problems associated with tests on production material, the material and the test performed are outlined below.

1. Guns

Every naval gun from 16″ caliber to machine guns is proved. The extent of the tests varies somewhat with the caliber and type of gun, but in general the guns must pass the following tests:

(a) They must stand pressures greater than the pressure developed in firing service ammunition.

(b) They must give projectiles the expected muzzle velocity, range, and accuracy, firing standard ammunition.

(c) Their recoil mechanisms must function properly so that undue forces will not be exerted on the gun mount and the ship's structure and, if automatic or semi-automatic, they must function at the proper speed.

(d) Gun mounts must stand the recoil forces of proof charges.

2. Powder

Powder (propellant) must be uniform and must give standard projectiles in standard guns the expected muzzle velocity with expected pressures and temperatures in the gun.

3. Projectiles

(a) They must pass flight tests which involve attaining expected muzzle velocities, translational and rotational, with standard propellants and guns, and must travel an expected range without undue precession or yaw and with expected accuracy.

(b) If armor-piercing projectiles, their ability to penetrate armor plate must be tested.

(c) If anti-aircraft projectiles, their time fuzes must be tested. Fuzes for other projectiles must also be tested to check against occurrence of duds and for accuracy of timing in delayed action.

4. Armor

Armor must be able to withstand attack by service projectiles at velocities and obliquities expected under battle conditions.

5. Bombs

Bombs are tested for flight characteristics and calibrated.

6. Bombsights

Bombsights are tested for accuracy and are calibrated.

FIG. 1. Taking micro-hardness readings on a steel sample with a Tukon tester.

FIG. 2. Spectrochemical laboratory, showing spectrograph and light source.

7. Explosives

Explosives (bursting charges) are tested for blast pressures, rate of burning, etc.

III

A number of technical problems are encountered in the above tests and are outlined below. The fundamental difficulty in most ballistic tests arises from the magnitude of the quantities to be measured and from the extreme rates of action and reaction involved. Some data may be gathered by very simple means; some require the best and latest instruments that are available.

1. The measurement of the velocity of projectiles must be made in tests of guns, projectiles, propellants, and armor at all scales from 0.30″ caliber to 16″ projectiles. In weight the subjects vary by a factor of about 150,000 but the method used is fundamentally the same. Velocities vary according to the type of test and the gun, approximately from a few hundred to 3000 feet per second.

All chronographs measure the time required for a projectile to pass between two fixed points in space. As the projectile passes a reference point it gives an electrical impulse to a recorder of some type by passing through a solenoid (in which case the projectile is magnetized) or by making electrical contact with the body of the projectile between two screens placed close together, or by passing through a photoelectric "screen."

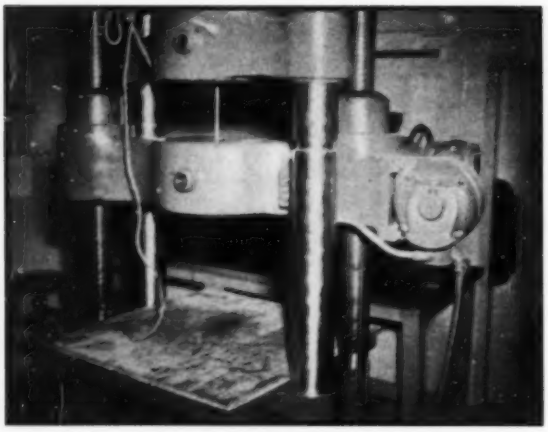


FIG. 3. Determining tensile strength of a cable.

The earliest device for recording and measuring the time interval between impulses from the two reference points was the Boulengé chronograph which uses the first impulse from contact screens to release a brass rod which then falls under the influence of gravity only and the second impulse to operate a knife edge which nicks the falling brass rod, the time interval then being deduced from the position of the nick of the second impulse on the rod. This system is still in limited use.

Until recently commercial oscillographs were modified to record the e.m.f.'s received from contact screens or solenoids. The time interval was determined by comparison with the record of a 500-cycle per second tuning fork, both records being taken on a strip of photographic paper on a revolving drum.

The latest chronographs are adaptations of the electronic counter circuit which has been widely used in investigations of short wave-length radiations. In the counter chronograph, the signals from the solenoids, contact screens, or photoelectric screens are used to turn on and off the counter circuit which, while on, counts and records the oscillations of a high frequency (100 kilocycle) e.m.f. standard. These instruments are capable of handling a great many more shots per day with a small operating staff and with a very much reduced chance for error. The counter chronographs in use at the proving ground are commercial instruments. The only adaptation which must be made for specific tests is in amplifying the signal from the passage of the projectiles by the reference points, since obviously the strength of the signal sent out by the projectile will vary greatly with the caliber of projectiles and the type of screen used.

2. Measurement of the pressure of the propelling gases in guns is very important for several reasons. Unusual pressures will disclose improper seating of projectile in the firing chamber, or improper rate of burning of the propellant powder. It is also necessary to measure pressure in proof of barrel shots in order to make certain that the gun will stand higher than normal pressures and thus have a reasonable margin of safety. A knowledge of the pressure developed is also important in gun design.

Accurate measurement of pressure is inherently difficult because of the short duration of the pressure (the order of 10^{-1} or 10^{-2} second), the fact that it is not constant (because of the rate of burning and change in volume), and the magnitude (up to 20 tons per square inch).

The earliest effective device for measuring interior ballistics pressures was the crusher gauge, a simple device by which a copper cylinder placed in the powder chamber of a gun was stressed on its plane surfaces by the powder gas. The residual strain produced, when compared with strains produced with static loads, indicates the maximum pressure attained. These crusher gauges, however, are not accurate to more than 0.3 ton per square inch, and considerable experimentation has been done to develop more accurate gauges which might also measure the pressure as a function of time. The piezoelectric

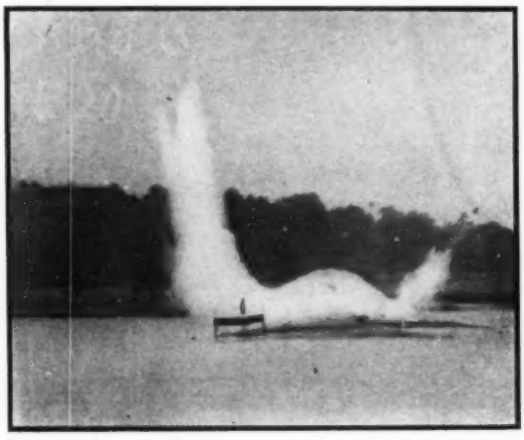


FIG. 4. Ricochet of 16" projectile.

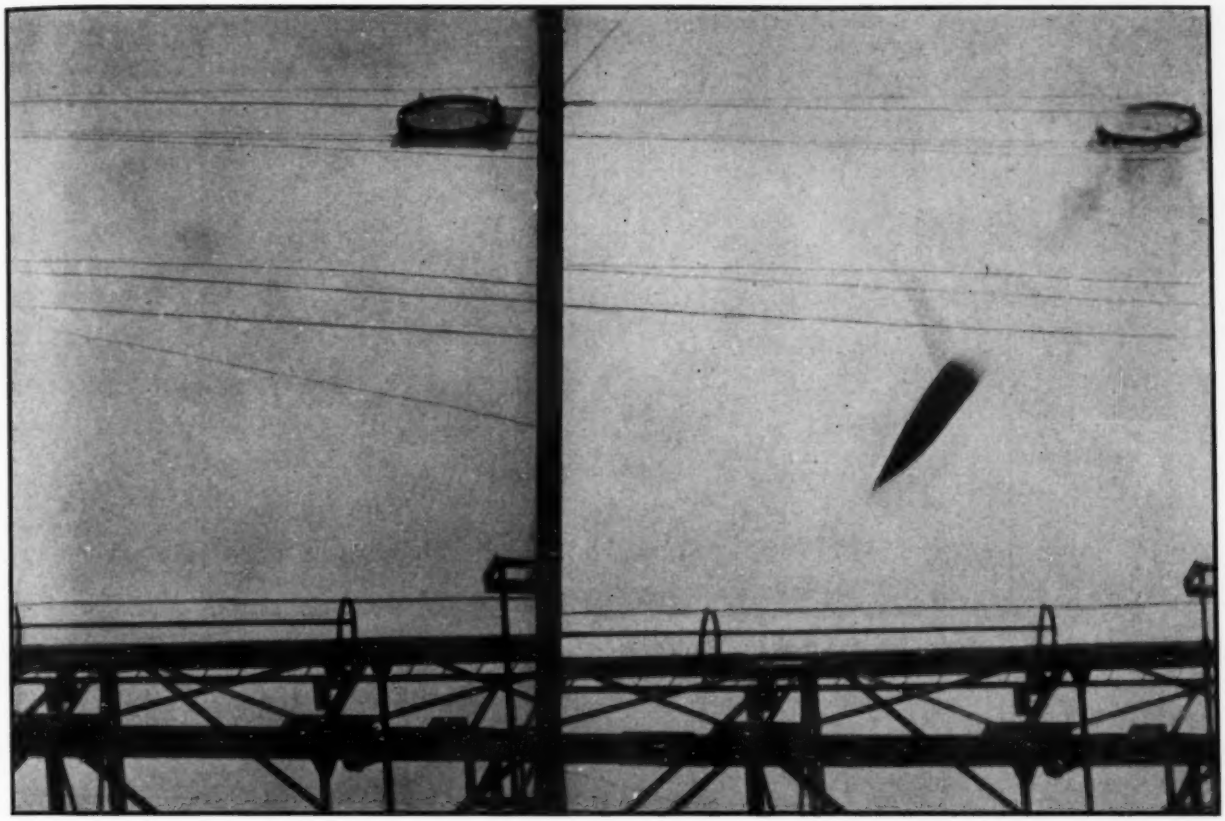


FIG. 5. A $\frac{3}{8}$″ plywood flight card before and after being hit by a 16″ projectile, showing the projectile in flight.

principle offers the most hope of a solution to the problem since there appears to be no reason for expecting that the short duration of the pressures measured would affect the piezoelectric currents, and inertial effects are held to a minimum. Piezoelectric pressure gauges have been used successfully in investigations on the propagation of shock waves from high explosives at the proving ground.

3. The forces on gun mounts (trunnions) and the rates of recoil and counter recoil are measured in routine.*

4. Certain tests of guns, projectiles, and powder require accurate measurement of the range of projectiles. This is accomplished by taking bearings on the splash of the projectile falling into the water with theodolites from several accurately located stations. The bearings are transmitted to a plotting center where the ranges are calculated. The interpretation of ranging data is complicated by the effects of atmospheric conditions on the flight of projectile. Corrections to observed point of fall must be worked out from a large collection of data on wind velocity, atmospheric pressure, humidity, etc., and on caliber and form of the projectile, muzzle, velocity, and elevation. A statistical section has as one of its principal tasks the problem of figuring out the effect of these varied factors on range. (The trajectory of projectile cannot be calculated by the methods of theoretical mechanics because the retarding forces cannot be accurately and simply described.) These data are then used in the interpretation of tests at the proving ground and are used in combat to improve the accuracy of gunfire.

5. The time of flight for all types of projectiles at all ranges must be known in order that range and bearing corrections can be made in directing gunfire at moving targets from moving vessels—

* These measurements are discussed in some detail in *Naval Ordnance* (United States Naval Institute, 1939).

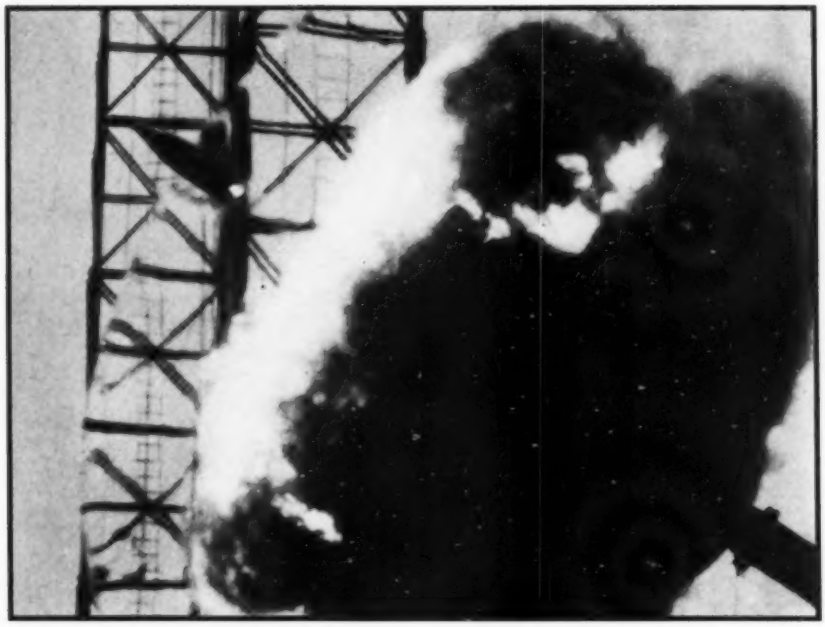


FIG. 6. 16″ projectile emerging from shock wave from muzzle blast of gun. The shock-wave front is seen passing through the middle of the projectile, ahead of the blast of propelling gas. The bright leading edge of the large cloud of propelling gas indicates combustion in air is in progress.

the conditions of gunfire between ships at sea. The angle which the trajectory makes with the horizontal at point of fall and its terminal velocity must be known so that the probable angle of attack of projectiles on enemy protective armor and its effectiveness can be foretold within limits. The importance of these data is easily seen. For instance, suppose two ships are steaming on opposite parallel courses at right angles to the line between them, 10,000 yards apart. If their speeds are each about 30 miles per hour, and a projectile is fired from one toward the other with no corrections for the ships' motion and time of flight, the projectile would fall more than 1000 feet astern its intended target. The calculated values of time of flight, angle of fall, and striking velocity which are given in the range tables can be checked by direct measurement.

Time of flight and terminal velocity (both direction and magnitude) are determined photographically by cameras which record the time at which the projectile leaves the gun and take pictures of the impact on the water and the projectile in flight just before impact.

6. Statistical methods find application in estimating the reliability of limited tests as an estimate of lot quality. The testing by actual trial of major caliber guns, projectiles, and armor costs up to $10,000 per round fired. Furthermore, many of the most important tests are destructive in that the material under test is either demolished (as in penetration tests of armor and projectiles) or lost beyond reasonable hope of recovery for re-use (as in flight tests over the water range). Therefore, the extent of every proving ground test on production material is a compromise between cost and reliability. Statistical methods must be used to estimate the reliability of limited tests as a means of estimating lot quality of armor, projectiles, and powder, etc., and as a means of estimating the efficiency and performance of guns, etc.; or to determine the extent to which the tests must be carried in order to determine the quality and performance within a required probable error.

7. The tests conducted on bombs, bombsights, and other aircraft instruments present technical problems quite similar to those of ranging projectiles. Every type of bomb must be calibrated so that its point of fall can be predicted when

dropped from a plane with a known ground speed and altitude. Here again, deviations must be correlated with atmospheric conditions. The tests and calibration of bombsights present similar technical problems.

In order to determine the velocity and altitude of a plane, and the initial boundary conditions of velocity and altitude for the bombs' trajectory, bearings in altitude and azimuth must be taken simultaneously from several stations at known intervals of time. The instant the bomb is released must be known to each theodolite station and the bearings of the bomb in altitude and azimuth are then continued on a common time schedule during its fall. The position and velocity of the bomb during its entire flight can be calculated from these data. Because the bearings from several stations must be taken on the same time schedule, the recording and measuring are more complicated than in ranging projectiles from guns. In the system in use at the proving ground, theodolite instruments are sighted on the object continuously by a telescope, and the bearings are recorded by cameras which take pictures of the theodolite scales at time intervals determined by a central radio signal which actuates the shutter mechanisms of the cameras at all stations simultaneously. Bearings taken at the release point are timed by a radio signal sent from the airplane at the instant the bomb is released.

8. Many special tests are made possible or are made more effective by the combination of photography and electronic triggering or timing devices. For instance, yaw is usually measured by placing a heavy pasteboard card in the path of a projectile, the yaw being shown by the ellipticity of the hole produced. This method can be effectively applied only for ranges at which a yaw card of reasonable size can be placed with assurance that it will be hit. Yaw measurements at long ranges are very important, however, because in addition to contributing to inaccuracy of gunfire, yaw may decrease the effectiveness of penetration of armor. Furthermore, a projectile may yaw at long ranges even though it apparently does not at short ranges, since although the projectile may be dynamically stable in flight when traveling a relatively flat trajectory at short ranges, it may be unstable as its linear velocity decreases and its path becomes more curved. Photography and electronics together can measure yaw at long ranges very effectively.

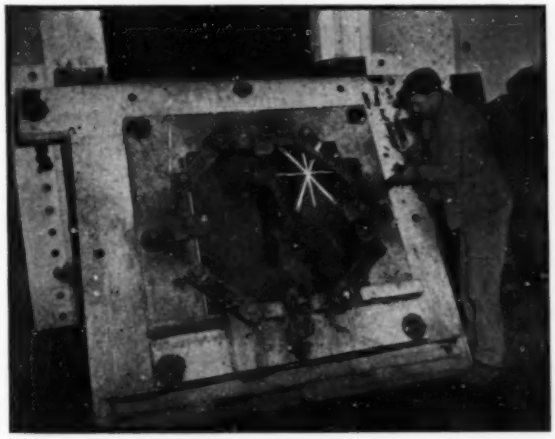


FIG. 7. Mounting experimental armor plate in adjustable butts for determination of limit velocity.

FIG. 8. A piece of light armor being removed from a salt bath electric furnace during heat treatment.

The ricochet of projectiles can also be photographed when the camera is equipped with a suitable triggering device.

The proving ground has an electronics laboratory in which the equipment for such special tests is developed as the need arises.

IV

The routine tests carried on at the proving ground over a period of years have made available a large accumulation of data which is useful in investigations of many ordnance and gunnery problems. One of these, mentioned above, is the deduction of correction tables from statistical

FIG. 9. Photograph of static detonation of a large bomb, in the center of the field of view. Flashes on objects to right and left of bomb are caused by the impact of fragments.

correlations of deviations in point of fall of projectiles and aereological data. Others are the effect of erosion of gun barrels (wear due to friction of projectiles, temperature, and friction of propelling gases), and interpretation of penetration tests on plates and projectiles.

1. The proving ground has a number of guns which are used extensively in the test of powder, projectiles, etc., until they are no longer useful. In contrast to guns destined for naval vessels, these guns are used enough and under proper conditions so that the effect of erosion can be observed progressively. Erosion is detected by measuring the bore diameter with a star gauge and by visual inspection.

Erosion is the principal factor governing the life of a gun. As the rifling in a gun barrel is worn away, the gun loses velocity (hence range) and becomes less accurate. It is well known that erosion is increased as the propellant charge in a gun is increased in an effort to attain higher velocities.

Erosion contributes to inaccuracy by increasing the tendency of a projectile to yaw in flight. The gun bore can become enough oversize so that the forward part of the projectile has considerable clearance and the axis of the projectile is no longer constrained parallel to the gun barrel, and the projectile can conceivably "rattle" in its passage through the bore; and, as the projectile leaves the gun barrel, the propellant gases will push the projectile in a direction not parallel to its line of flight, thus increasing yaw and even "tumbling" the projectile in some infrequent cases. Also, the rifling of the gun barrel may become so worn that it does not properly engrave the rotating bands of projectiles and does not give them the rotational velocity for which they were designed.

It is generally believed that the principal cause of wear on the bores of major caliber guns is the heat, friction, and chemical activity of the propelling gases, and that friction between the projectile and the bore is of minor importance. Erosion does not appear uniformly along the length of the barrel; it is most severe at the breech end of the rifling and at the muzzle end.

Data taken at the proving ground on erosion are useful in two general ways. First, conclusions may be drawn correlating erosion or total number of rounds fired in a gun with decreases in velocity, and estimates of the useful life of guns in rounds fired can be made. Second, conclusions can be drawn as to the effect of various factors in different gun designs on erosion rate.

2. From tests of armor and projectiles, data are available on the penetration characteristics of a wide range of projectile calibers and armor plate thicknesses. This has made possible an extensive investigation into the general penetration phenomenon, and particular attention has been drawn to the problem of scale effect to answer two questions. First, can a general penetration theory developed from extensive experiments at one scale (say 3″ caliber projectiles) over a wide range of e/d (ratio of plate thickness

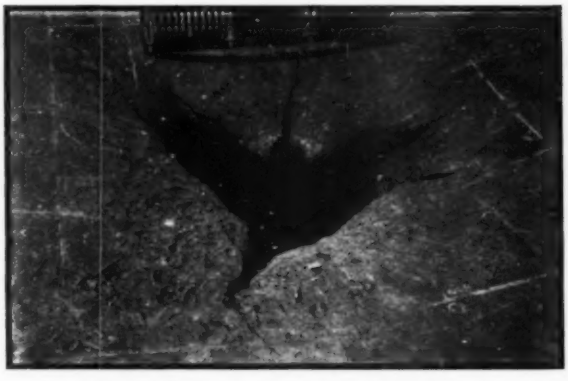


FIG. 10. The result of static detonation of a large bomb in contact with armor plate.

to projectile diameter) be applied to penetration at a different scale? Second, can the quality of major caliber armor plate be determined by making penetration and other physical tests on relatively thin sections of thick plates? These questions are of great economic as well as military importance, because the cost of plate and projectile tests varies approximately as the cube of the scale at which the tests are conducted. The money cost of extensive experimental investigations at 16″ scale would be prohibitive and would be too great a drain on critical materials in time of war. The cost of the same experiments at 3″ scale is comparatively insignificant, but the knowledge gained would be of only minor value if it could not be applied to larger scales.

Armor and projectile quality are measured at the proving ground in terms of limit velocity. In interpreting plate penetration data, the limit velocity, plate thickness, projectile diameter and mass, and obliquity θ (angle between the trajectory of projectile and the normal to the plate), are used in calculating a plate penetration coefficient which has been shown to be a function of the ratio e/d and θ.

This plate penetration coefficient reduces penetration data to a form in which penetration can be compared at different scales. The problem is complicated, however, because penetration varies with projectile form and physical properties, and with armor type (face hardened or homogeneous) and physical properties, and these factors cannot be incorporated into a general coefficient.

Records of the proof of armor and projectiles taken over a number of years are used extensively in investigation into penetration phenomena. In addition, a laboratory is maintained exclusively for research on armor and projectiles at a reduced scale. The facilities of this laboratory include a special firing range for ballistic tests, and equipment for physical and chemical research on armor and projectile steel.

The ballistic testing program at reduced scale includes extending penetration data over wider ranges of the e/d ratio than have been heretofore available, using guns of 3″ caliber and smaller; and investigating the penetration phenomena of experimental projectiles (as to form, composition, and physical properties) and experimental plates (as to composition and physical properties). The laboratory has electric furnaces and quenching facilities for heat treating armor and projectiles, a large saw to section heavy gauge armor for testing at reduced scale, physical testing equipment for determining strength and hardness of steel, a well-equipped metallographic laboratory including a Bausch & Lomb metallographic microscope, a chemical laboratory, including apparatus for gas analysis of steel, a spectrochemical laboratory equipped with a Bausch & Lomb large Littrow quartz spectrograph and University of Michigan light source and microphotometer, a 110-kilovolt x-ray diffraction camera with a Coolidge type tube, and equipment of the Edgerton type for flash photography of projectiles in flight and in impact on armor.

Official U. S. Navy Photograph

A Martin Mariner, a twin-engine, gull-wing patrol bomber of the type used by the Navy on anti-submarine patrol, for the protection of convoys, and as a cargo carrier for the Naval Air Transport Service.

Research in the Bureau of Aeronautics

BY CAPTAIN L. C. STEVENS, U.S.N.

Deputy Director of Engineering for Experiments and Development

CAPTAIN
L. C. STEVENS

AS a matter of fundamental policy, the Bureau of Aeronautics does not itself engage in research, but rather makes military applications of the results of research. Research, as defined specifically by Funk and Wagnalls, is "a systematic investigation of some phenomenon or series of phenomena by the experimental method to discover facts or to coordinate them as laws." The Bureau of Aeronautics is fortunate to have the aeronautical research function, the general investigations common to all aviation, excellently performed for it by the National Advisory Committee for Aeronautics, which was established by law at the end of the last war to fulfill this aim for the Army, the Navy, and for civil aviation.

The Bureau holds ex-officio membership on the Committee itself, as well as in its numerous specialized subcommittees, and in time of war the Committee is placed directly under the Aeronautical Board, which is in effect the Army and the Navy. The Committee is, however, a separate entity from the Army and Navy, obtaining its own funds from Congress, establishing its own facilities, and administering its own personnel, all for the greater good of American aviation in general. Much of the work accomplished by this excellent organization is done at the specific request of the Navy.

This peculiarity of national organization has a great deal to do with the organization of the Bureau of Aeronautics itself for research in the more colloquial sense which includes all experimentation and development. It has made it possible to keep the Bureau's own activities within such a compact compass that the results of research can be applied with the most intense and hard-boiled practicality.

The Bureau's organization is essentially intended to insure that the same engineering personnel who initiate and administer experimental projects, also deal with the defects and troubles in existing service articles. There are about a dozen highly specialized offices dealing with such separate matters as aircraft armament, instruments, power plants, radio and electrical equipment, shipboard applications, materials, miscellaneous equipment, structures, or aerodynamics. There are also nearly as many separate offices, each of which deals with a different type of aircraft. The Radio and Electrical Branch is responsible for the development of new and advanced radio equipment, and for the installation and servicing of it as long as it remains in service, whereas the Dive Bomber Design Branch is responsible for the development and servicing of dive bombers, including the effect on both the airplane and its employment of that same radio equipment. The Design Branches for the various types of aircraft function essentially as coordinators, much as though a project engineer continued with his project through its development period, its production, and its subsequent service life.

There are other specialized contributing offices, such as one which forms the link between research and its embodiment in aircraft by determining the state of the art through analytical short cuts, another which checks this work by carrying through actual designs; one which analyzes and criticizes contractors' proposals, another which prepares specifications, and still another which coordinates the experimental effort as a whole. It is important to note that practically all of these branches contain commissioned officers with combat experience as well as civilian engineers and technicians.

All of these branches are within the Engineering Division. The Military Requirements Division of the Bureau is entirely independent of the Engineering Division. Composed entirely of commissioned officers with combat experience, it

represents the operating viewpoint as distinct from the engineering viewpoint. It is the link between the Bureau on the one hand, and the Commander in Chief and the Fleet on the other hand. It determines and establishes the military requirements that are to be satisfied in the materiel that is furnished. The practical result of this organization is that in general, no projects can be initiated or carried through to completion without agreement between the Engineering Division and the Military Requirements Division, one acting as a check and balance on the other.

The Procurement Division exercises the contractual relations of the Bureau in experimental work as well as production orders, the Production Division supervises the inspection service in the field and the many complex aspects of the production effort, and the Maintenance Division cares for overhaul, upkeep, and the determination and distribution of spares. The establishment of the program of new aircraft, aircraft intelligence, personnel, training, and operations is handled outside the Bureau of Aeronautics.

In addition to the fundamental aspects of aeronautical research, which are handled by the National Advisory Committee for Aeronautics, there are many individual *ad hoc* problems of a purely aeronautical nature, usually connected with the development of a specific model of airplane. The wind tunnels, towing basins, and laboratories of the aviation industry and of the universities are utilized for such work, although some problems are of such a nature that they must also be handled by the National Advisory Committee, because of the specialized equipment required which is not available elsewhere. The Navy also has facilities of its own for such immediate problems, at the Washington Navy Yard and at Carderock, Maryland.

There are many research problems which are not of a purely aeronautical nature in which the Bureau is vitally interested. These cover a wide field, from armament and explosive developments to almost every class of raw and fabricated material in engineering use, from the development of electronics to fishing tackle and concentrated food, from repelling sharks to repelling Japs. Here again the Bureau of Aeronautics follows its fundamental policy of restricting its own efforts as far as possible to applied engineering, and makes maximum use of other government agencies and private enterprise, to accomplish the research that may be involved. Through various specialty branches of its organization the Bureau holds membership on literally scores of interlocking committees through which a part of this work is initiated, and provides a large number of liaisons for its guidance and for coordination with other agencies, such as the Army Air Forces, which are interested in the same problems. These working contacts prevent duplication of effort in addition to providing channels of necessary information for eventual application purposes. The National Defense Research Council has been of inestimable value in research utilized directly by the Bureau of Aeronautics, and important contributions have been made by the Bureau of Standards, the Public Health Service, the National Inventor's Council, the War Department, the Forest Products Laboratory, the various naval Bureaus of Ordnance, Ships, Medicine and Surgery, Yards and Docks, and many others, including a large number of commercial organizations working either on contract or gratuitously.

The Bureau applies the results of research not only to new designs of aircraft, but also on a large scale to existing aircraft by modifying them where this can reasonably be done without interferences with production, and by continually improving the equipment which they carry. The experimental work which must precede such applications is largely done at the Naval Air Material Center in Philadelphia and at the Naval Air Station, Patuxent River, Maryland, although various training and operating organizations of the Navy are also used, as well as private contractors.

The scale of the effort that is organized and guided by the Bureau of Aeronautics is complex and very large. There are nearly a thousand projects at the moment placed in the Naval Air Material Center alone. Such an effort is expensive, but the support of Congress in providing adequate funds has been unfailing. The Navy has already demonstrated that it is not only superior in quality to enemy naval aviation, but to Japanese land-based aircraft as well. In return for the experimental effort that is now being put forth, it fully intends to maintain this ascendancy in the future.

The Naval Air Material Center, Philadelphia, Pennsylvania

By John W. Meader, Management Consultant, N.A.M.C.

Captain S. J. Zeigler
Commanding Officer

THE Naval Air Material Center, Philadelphia, was organized in July, 1917 as the Naval Aircraft Factory for the sole purpose of manufacturing aircraft. At that time, commercial plants were unable to supply Navy requirements because their entire output was taken by the Army. At first a department of the Philadelphia Navy Yard, the Naval Aircraft Factory broke ground in August, 1917 and produced its first aircraft, a Curtiss H-16 flying boat, in March, 1918.

With the establishment of the Bureau of Aeronautics in 1921 and transfer of the Naval Aircraft Factory to its control, the guiding policy tended to concentrate the factory's work on experimental aircraft and accessories. In accordance with this long range policy of developing a Naval Air Center at Philadelphia, the Aeronautical Engine Laboratory was transferred there from the Washington Navy Yard in 1924. A landing field was added in 1926 and some considerable work of modifying service aircraft for special purposes was begun.

By this time, aircraft, ordnance material, catapult and arresting gear, engine and parachute manufacture were part of the factory's work, although on a small scale, and laboratory test work was becoming a large and increasing item.

During the intervening years, especially since 1939, the research and experimental activities of the Air Center have been greatly expanded while manufacturing work has been confined more and more to the pilot-line production of new types of aircraft and miscellaneous work on material not commercially available.

At the present time, the facilities of the Air Center occupy nearly two million square feet of floor space, and thousands of persons are employed, and the annual budget is close to fifty million dollars. Whereas, in the beginning the Naval Aircraft Factory had only one project—the manufacture of flying boats—there are now on the books of the Air Center nearly one thousand different projects, mostly of an experimental nature.

The simplicity of the original organization could not cope with the growing complications of these myriad assignments. Early in 1943, plans of reorganization were drawn, which became effective last summer, transforming the old Naval Aircraft Factory into what is now the Naval Air Material Center, Philadelphia.

As shown in the organization chart the Center includes four separate commands. The Naval Aircraft Factory now carries on all miscellaneous manufacturing work which involves serial production, together with the pilot-line output of new, improved models of naval aircraft. The Naval Aircraft Modification Unit is engaged in adapting standard service-type Navy airplanes to special purposes.

The Naval Air Experimental Station is a group of four research and test laboratories. The Aeronautical Materials Laboratory makes static and dynamic tests of complete aircraft, parts, materials, and accessories, chemical tests in which the prevention of corrosion under the severe conditions of naval operation is a primary object, and metallurgic tests. The Radio and Electrical Laboratory makes type tests of commercial equipment and also works on the development and improvement of the electrical equipment which has now become so important a part of naval aircraft. The Aeronautical Engine Laboratory tests and calibrates all new aircraft engine models used in naval aircraft and assists in the development of new engine types. It

Official U. S. Navy Photograph

FIG. 1. Administration Building.

conducts tests of engine accessories, fuels, and lubricants. The Instrument Development Laboratory, as the name implies, is concerned even more with the experimental development of wholly new aircraft instruments, than with testing of commercial products.

The Naval Auxiliary Air Station, Mustin Field, conducts local flight operations, and, in addition, carries on an important part of the flight testing of new military aircraft, especially those features concerned with the operation of the launching and arresting gear of the Navy's aircraft carriers.

The Naval Air Material Center, as a whole, thus functions as a completely self-contained development group, intimately associated with the design and development of experimental aircraft.

Control of this activity begins, of course, in the people of the United States and passes successively through Congress, the President, and the Secretary of the Navy, reaching the local establishment through two Navy channels—the Commandant of the Fourth Naval District, general administrative matters (other than technical), and the Bureau of Aeronautics, which assigns the work projects and allots the funds to carry them out.

The present Commanding Officer is Captain S. J. Zeigler, Jr., U.S.N., who took over the management of the Center in May, 1943, following the untimely death of Captain W. W. Webster, in an airplane crash.

The policies under which the Center operates are laid down, of course, in the Bureau of Aeronautics. This policy, for years, has emphasized the importance of the Center as a research, experimental, and development institution. The practical results of this policy are to be found in almost every military and commercial airplane in existence today.

It is well known that the Navy pioneered in the development of the radial air-cooled engine, although it is not so well known that the Naval Air Material Center played a large part in this development from its beginning.

At a very early date, the Navy appreciated the importance of metal in aircraft construction, but had very severe problems of corrosion to solve before light metal alloys could be successfully employed. Naval aircraft operate under conditions of salt spray and exposure almost unknown to land-based aircraft. The anodic treatment of aluminum alloys was the outcome of early efforts by the Naval Aircraft Factory to find some practical way of dealing with salt water corrosion.

Similarly, the development of corrosion-resistant steels for aircraft use was advanced an important step when N.A.M.C., with the cooperation of the aircraft industry, was able to develop methods of forming stainless steel sheet into the complicated shapes of exhaust manifolds.

Another example of the Air Center's contribution to the present efficiency of the Naval Air Service, which is not widely known outside Navy circles, is in the development of the catapult and arresting gear used by the carriers. The present equipment is considered the finest in the world.

In the rapid development of electronic technique the various commands of the Naval Air Material Center have played an important part. Some of the applications of the newer high frequency transmitters and receivers are little short of fantastic in the results they may be made to achieve.

The belief is generally held by the public that naval aircraft, especially carrier-based aircraft, have to operate at some disadvantage in comparison with land-based aircraft, owing to the necessity of providing for extremely short take-offs and arrested landings when operating from the limited confines of a carrier deck. Actually, it has not worked out that way, for carrier-based aircraft are not measurably inferior in any respect to land-based types. Probably one of the

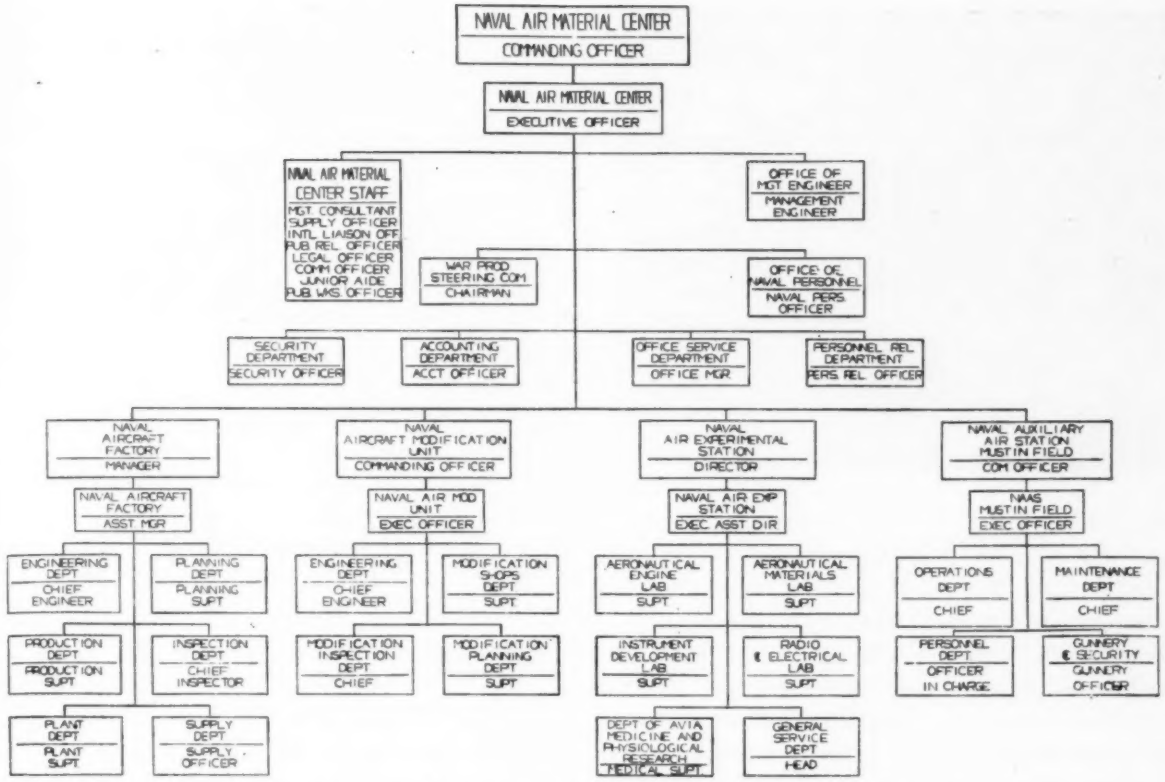


FIG. 2. Chart showing the organization of the Naval Air Material Center, Philadelphia, Pennsylvania.

reasons for this success in overcoming what appears to be a fundamental handicap in naval aircraft is the intensive program of development and testing they are made to undergo before they are placed in service.

In its experimental and development work, the Naval Air Material Center draws freely on other research agencies, not only to avoid duplication of effort, but also to gain the advantages of mutual assistances, criticism, and advice. Test reports are interchanged at frequent intervals with the corresponding Army establishment at Wright Field, Allied liaison officials, the Bureau of Standards, the National Advisory Committee for Aeronautics, and many other government and semi-official agencies. Cooperative research projects are frequently undertaken. Especially in its relations with the aircraft industry, N.A.M.C. both draws freely on their experience and technique and pays back to cooperating companies the authoritative and valuable information of its test reports. Test projects are frequently held open for months in order to permit manufacturers whose equipment has failed on its initial tests to modify and to improve their products with the help of Air Center engineers.

These engineers and their assisting technicians are the backbone of the research and experimental organizations. Although the number of personnel has increased sharply since the war began, most of the civilian employees occupying the key positions have been associated with the Air Center for many years, providing a continuity of direction and effort, within the framework of Bureau of Aeronautics policy, which could hardly be obtained in any other way.

As the work of the Air Center has expanded, and the problems encountered in the evolution of service aircraft have become more and more complex and urgent, new research facilities have had to be provided in a continuing series of additions and betterments.

Engine-test facilities at the Air Center now include equipment for submitting complete power plants to the conditions of temperature and pressure associated with substratosphere opera-

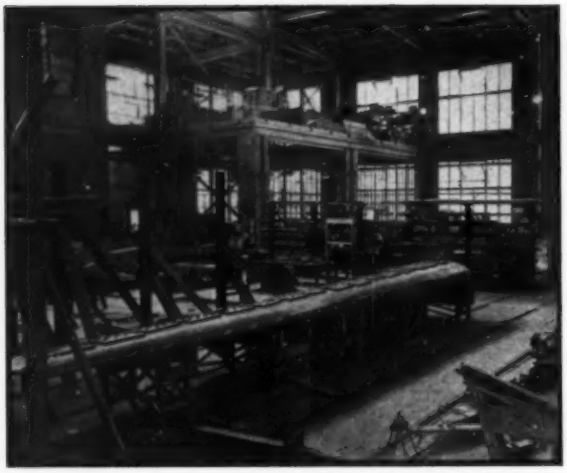


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FIG. 3. Interior view of Aeronautical Materials Laboratory. Airplane wing under static test.

tion. Similar equipment is available for elaborate study of the physiological effects of altitude conditions.

The structural laboratory has taken on increasing importance as aircraft design has become increasingly indeterminate. As the experimental physicist will readily appreciate, pioneering work often requires the development of new and ingenious instruments. For example, it was recently found, in the development of a flight testing project, that entirely new telemetering equipment would be required in order to realize the full advantages of the new test methods.

For the flight testing of naval aircraft and their associated carrier equipment, installations of actual catapult and arrested-landing devices have been made on Mustin Field. One of these installations is in the form of a large turntable which simulates a carrier deck and may be aligned with the direction of the wind.

The shops of the Naval Aircraft Factory, although not intended for large scale production, have had to be kept abreast of rapid developments in aircraft production technique. As the aim here is the pilot-line production of new aircraft, up to the point where completely proven manufacturing descriptions may be turned over to private industry, a very wide variety of tools and equipment has had to be provided.

Mention was made above of the large number of projects—approximately one thousand—now on the books of the Naval Air Material Center. This great variety of assignments has imposed a problem of work planning not often found in industrial establishments.

As the work assignments are of various degrees of urgency, the Bureau of Aeronautics, which is in close touch with the forces afloat and abroad, indicates their relative order of importance by dividing them into five priority groups, lettered *A* to *E*. Definitions are carefully drawn to indicate the urgency of each group of projects. Thus, *A* projects are of the greatest military urgency to be expedited to the utmost, and regardless of adverse effects on projects of lower rank. At the foot of the scale, the *E* group embraces projects which promise to advance the state of the art, but are reserved for facilities and personnel not required on projects of higher priority.

Under this scheme, *A* projects are confined to emergency items. *B* projects are those which have been singled out for preference, while the bulk of the work normally lies in the *C* and *D* categories. The *E* group is not likely to be reached during the war. If no new assignments were received, their turn would come after six months' delay, but up to the present time the stream of incoming urgent work has shown no sign of diminishing.

The planning problem is complicated not only by the large number of projects on hand, but also by their great variety. A recent analysis showed 39 distinctly different kinds of work on hand—different in that each would require for most efficient prosecution, its own distinctive facilities and specialized personnel. In this analysis, the pilot-line production of new aircraft,

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FIG. 4. PBN—1 airplane manufactured at N.A.M.C.

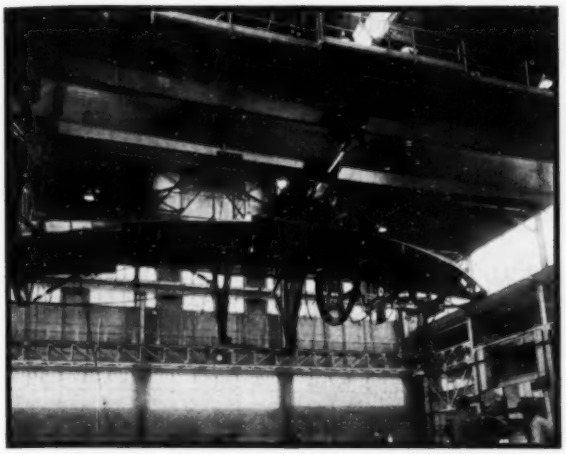

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FIG. 5. PBN—1 hull manufactured at N.A.M.C.

which would be an ambitious and ramified undertaking in itself, was counted as only one kind of work.

As the Naval Air Material Center has virtually no choice in the work which comes to it, its planning efforts have been directed almost entirely toward subdividing the work load into parcels of more convenient size. Thus, in an equal division of the work each of the four commands, with its own planning department, would have only 250 projects to schedule. Actually, the division is unequal; nearly 70 percent of all projects are consigned to the Naval Air Experimental Station, where they are further subdivided among the four laboratories, and in each of those into various sections charged with their own specialized activities. The projects of the Naval Aircraft Factory, although smaller in number, are naturally much more complex in the planning and production control work required for proper timing and coordination of the mass of detailed tasks which often go to make up a single manufacturing job.

The central administration of N.A.M.C. also has need of a special planning section. Here, the periodic reports of the four operating commands are consolidated and listed for convenient review by the Bureau of Aeronautics. This summary brings the Bureau up to date on the state of work in process, and indicates its current division according to priority. With the latest advices from naval operations before it, the Bureau adjusts the priority ratings of individual jobs at N.A.M.C. when and wherever necessary.

The object of this system, of course, is to gear the activities of the Air Center as closely as possible both to the needs of the fleet and the developing plans for continuous improvement of naval aircraft.

Research in the Bureau of Supplies and Accounts

BY REAR ADMIRAL W. B. YOUNG, SC, U.S.N.
Chief, Bureau of Supplies and Accounts, and Paymaster General

REAR ADMIRAL
WM. B. YOUNG

THE Containers and Materials Handling Section of the Stock Division is one of the principal research agencies of the Bureau of Supplies and Accounts.

The Stock Division, as the name implies, concerns itself with the flow of virtually all Navy materials with the exception of technical items of ordnance, aeronautics, and medical stores. The Containers and Materials Handling Section, staffed almost entirely by experts drawn from private industry, carries on considerable research in conjunction with other naval and government agencies, and the large manufacturing firms which supply all manner of articles for shipment overseas.

Aside from the experimental testing function on new materials carried on largely at the Naval Clothing Depot, this section conducts a program of container standardization and materials handling which has inaugurated many worthwhile practices in the packaging and shipping field.

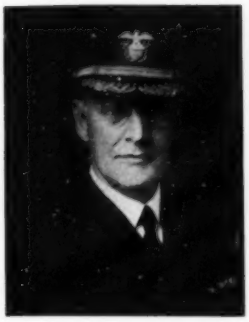
The training courses in shipping methods and materials at the Forest Products Laboratory, operated by the Department of Agriculture, have been extensively utilized by the Navy, among other services, in the training of both naval and civilian personnel and Navy contractors' personnel. It is suggested that a more accurate description of the research activities and training programs undertaken by the Forest Products Laboratories can be obtained directly from this activity.

Research and experimental work in the field of containers and materials handling is conducted largely in conjunction with industry engaged in producing materials and equipment applicable to the entire field of packaging, packing, and movement of material. A list of products utilized in accomplishing this purpose would be voluminous. Suffice it to say that examples are: paper, wood, glass, metals, plastics, asphalt products, rubber, textiles, vegetable and animal products, and by-products in the field of containers, and diverse equipment for materials handling, such as tractors, lift trucks, hand trucks, conveyors, skids, pallets, etc. The factors to be considered in such a function vary directly in proportion to the number of articles used by the Navy, the methods of production, the mode of transportation, the handling, storage, and issue conditions at intermediate and final destination points, and, in the final analysis, are predicated upon the requirements of a fleet operating in all the seas of the world.

A large share of the research and experiment in connection with the shipping of material is devoted to the development of packaging, packing, and preservative materials which will more adequately preserve, protect, and transport the product, and at the same time conserve or replace critical materials and effect savings in man power, shipping and storage space, and time.

Research in the Bureau of Medicine and Surgery of the U. S. Navy

By Rear Admiral H. W. Smith, MC, U.S.N. (Ret.)



Rear Admiral H. W. Smith, MC, U.S.N. (Ret.)

I. ORGANIZATION OF NAVAL MEDICAL RESEARCH

TWO years prior to Pearl Harbor, a sudden impetus was given to medical research in the Navy by the establishment of a Research Division in the Bureau of Medicine and Surgery. This was the first step in this direction since World War I.

The Research Division was charged with the following three major tasks:

1. Initiating, encouraging, and coordinating medical research in the Navy;
2. Maintaining exchange and advisory liaison with all agencies concerned with research and development of medical import;
3. Operating the general informational service required to establish a base from which research may profitably be projected.

Many medical problems of the war are closely related to engineering developments. Consequently, four laboratories at (1) New London, Connecticut, (2) Pensacola, Florida, (3) New River, North Carolina, and (4) Cedar Point, Maryland, have been established to study matters pertaining to men in relation to war machines. In these laboratories, equipment is tested or perfected, protective measures are developed, and methods of selecting personnel or improving the human functions are worked out. The medical research laboratory at New London studies medical problems arising from subsurface warfare; the Pensacola, Florida and Cedar Point, Maryland laboratories are concerned with the aviator's reactions to flying conditions; while the laboratory at New River, North Carolina studies problems arising from amphibious and Marine Corps operations. To the Naval Medical Research Institute (commissioned October 27, 1942 and administered by the Medical Officer in Command, National Naval Medical Center at Bethesda, Maryland) is left the field of fundamental medical research.

The Research Division of the Bureau of Medicine and Surgery assigns problems to the various laboratories. It may be compared to the central nervous system, to which stimuli come from the field and from which impulses initiating and coordinating research activity flow to the various laboratories.

II. PROBLEMS OF NAVAL MEDICINE

Naval medicine is frequently spoken of as being itself a specialty. This statement is untrue, for naval medicine embraces every form of specialist practice. Even in the case of activities aboard ship and in the field, the principles and practices of universal medicine are followed. Naval medicine, then, is medicine differing from civilian medicine only as required by the peculiar field of application. There is, however, a slight difference in its primary purpose. Whereas civilian medicine aims to improve the welfare of the patient, military medicine has as its mission the conservation of military strength. But even this distinction is more apparent than real for in civil practice consideration for the patient must on occasion yield place to the social good, as in case of contagious disease. The good of the aggregate is a superior loyalty, and one which needs no sophistry to justify it. Medico-military research in its effort to improve resources and increase knowledge to the end that there shall be no avoidable loss of personnel or diminution of its effectiveness is acting in accordance with that superior loyalty.

While current investigation has as its immedi-

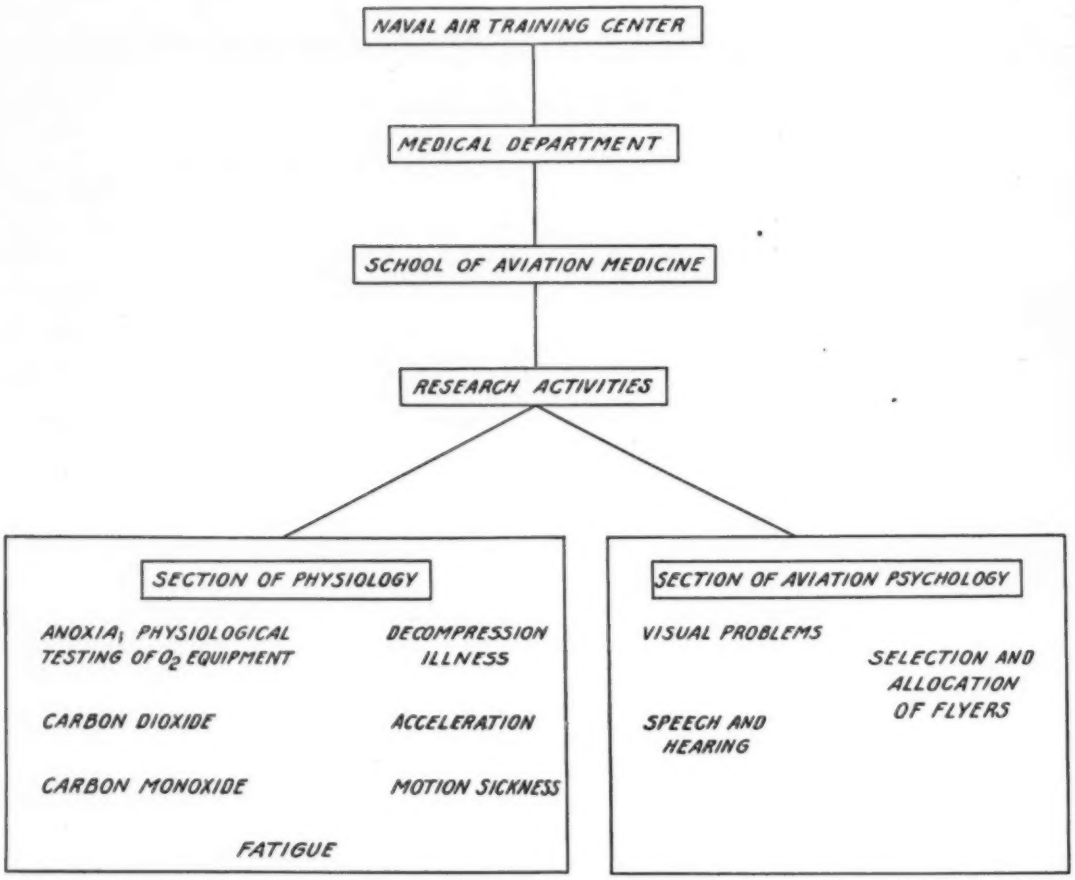


FIG. 1. Chart showing the organization of the Naval Air Training Center.

ate purpose making useful contribution to our war effort whether in promoting military effectiveness, in strengthening our home front, or in reclaiming the casualties of war, it holds also full promise of adding immeasurably to our understanding of the needs of the human body, its responses to environment, injury, and disease, and means of influencing its resistance and recuperative powers.

Some of the interesting research problems being solved by the staff of forty-eight research workers of the Naval Medical Research Institute deal not only with disease, injury, diet, and protective clothing but also with the development of special techniques such as the use of the electron microscope for medical purposes and the development of a special camera for discovering tuberculosis. The latter, an automatic photofluorographic camera using 35-mm non-perforated film, photographs the x-ray shadows produced on fluorescent screens during chest surveys for tuberculosis. A new method which holds much promise has been devised for making sections of tissue, organs, or bacteria thin enough for use with the electron microscope. Such sections must be of the order of 0.1 to 0.3 micron in thickness and when available will permit work on large numbers of problems ranging from a study of the relationship of virus to cytoplasm in inclusion bodies, to detailed analyses of myofibrils in muscular atrophy, or collagenic fibrillae in connective tissue disturbances or wound healing.

A battle dress has been designed at the Naval Medical Research Institute, for the purpose of giving the greatest possible protection against flashburn, drowning, blast injuries, and missiles. Attempts are now being made to incorporate light body armor into this battle suit.

Other researches range from studies of new methods of treating malaria to the effect of storage on liquid plasma during its second year, to studies of susceptibility to decompression or "bends," to research on the vitamin content of naval flight rations as affected by their cooking, and the development of a "tablet emergency ration" made chiefly of sucrose candy, sucrose fat candy, and malted milk tablets which laboratory experiments as well as trials at sea have proved to be much preferable to the usual abandon-ship ration of biscuits, meats, and chocolates.

To date seventy-three research projects and thirty minor investigations have been assigned by the Research Division, Bureau of Medicine and Surgery to the Institute. Fourteen of the major and twenty-three of the minor projects have been completed.

FIG. 3. Applied psychology laboratory. Measurement of hand tremor. On the right are two subjects having their hand tremor measured on a steadiness test designed at NMRI. It is possible for the operator to measure four subjects simultaneously on this instrument.

III. RESEARCH IN MEDICAL AND ENGINEERING PROBLEMS OF SUBSURFACE WARFARE

The Medical Research Laboratory located at the U. S. Submarine Base, New London, Connecticut has done much research on tests which are used in selecting submarine personnel as well as in methods of testing and training their visual and auditory senses. A special school for pharmacists mates entering the submarine service is also conducted there.

Before the war, the selection of submarine personnel was made entirely on the basis of physical fitness, as measured by the standards set forth in the Manual of the Medical Department (Par. 1535). However, the general personnel problem became so acute that it became necessary to widen the scope of the examination for submarine duty, so that it now includes instead of the stringent restrictions of the manual, a thorough physical examination, an examination of the individual's intelligence, mechanical aptitude, personality traits, and of his emotional stability.

Official U. S. Navy Photograph

FIG. 2. Research building, School of Aviation Medicine, Pensacola, Florida.

Emotional stability is one of the prime requisites in a member of a submarine crew because of the trying conditions under which he must live. Bad as these conditions are in the temperate climates, imagine what they must be in the tropics: excessive crowding; high temperature; sleepless nights; extreme humidity; canned food; the decks awash with sweat; no glimpse of the sun—all this for two months on end.

To these physical discomforts are to be added the effect of an abnormal mode of life and of constant strain, for it must be remembered that the submarine is the hunted as often as it is the hunter. It is the object of relentless search by surface craft, planes, and other submarines. There are listening devices all about to detect the slightest sound which might indicate its presence, and being systematically depth-bombed is nonetheless harrowing for being a daily experience. Under such conditions morale sags.

FIG. 4. Plasma research laboratory. Chemical and physico-chemical studies on plasma. Apparatus on left of chemical bench measures the osmotic pressure of plasma and other fluids. This is an indirect measure of the "anti-shock" effectiveness of the fluid.

Probably because an effect of saturation with moisture is the cleansing of the air of particulate bodies, and because bacteria adhere to the wet surfaces, there is virtually no communicable disease notwithstanding the indescribable crowding. Three important problems of subsurface warfare are: providing air-conditioning to make the atmosphere tolerable; alleviating that complex termed "fatigue"; and compensating for nutritive deficiencies, especially loss of salt and water-soluble vitamins eliminated in sweat. In fact, the sweat of submarine crews in the tropics is a highly vitaminous fluid! These problems have been solved to such a degree that now the factors terminating a submarine patrol are more likely to be failure of materiel than exhaustion of personnel.

Large groups of individuals are given tests of various kinds such as general intelligence, mechanical aptitude, personality traits, etc. They are scored not only on the results of "paper and pencil" tests but on the basis of machine tests, interviews, school grades, and performance in the submarine escape training tank. As they progress through various stages of training their work is compared with their achievement on the tests. Wherever possible the results are finally checked with performance reports returned by commanding officers following at least one war patrol at sea in a submarine.

The constant comparison of performance records with test data yields the following results: (1) It distinguishes those persons who are prone to emotional disturbance. (2) It leads to the development of scoring methods from which predictions can be made for later populations as they are tested. On the basis of the success of the predictions the validity of the tests and performance records are checked.

One of the most interesting examples of the tests made to determine emotional stability is a two-hand coordination device. In this test a small disk moves about eccentrically on a horizontal plane, and the subject's instructions are to maintain a second disk in contact with the first by turning the two cranks. The diametrically opposed cranks operate lead screws to the second disk so that by appropriate manipulation of the cranks it is possible after some practice to maintain the two disks in contact throughout the entire course of the eccentric movements. The percent time of contact for each trial is registered electrically. The manner of learning this task affords an index to the probable degree of emotional stability of the individual tested.

Working in the field of acoustics, the laboratory has developed a system of selection of operators for sound-listening gear. Along with the usual

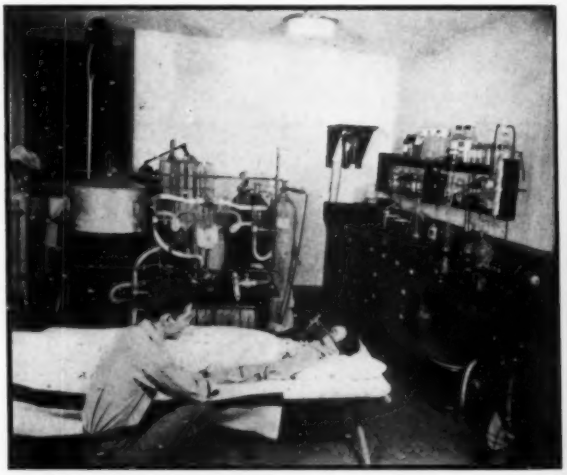


FIG. 5. Radiobiology. Apparatus and experimental arrangements for determining exchange rates of inert gases. The subject inspires the inert gas containing a small amount of radioactive isotope. The rate of tissue saturation is determined by placing a Geiger counter in the subject's hand; in the picture the latter are hidden from view inside the shield seen below the table.

tests of general intelligence and mechanical aptitude which in this case includes a technical knowledge of rule-of-thumb physics and mechanics, specialized tests of auditory acuity, pitch discrimination, tonal memory, rhythm, rate, time, and timbre are given. This battery of tests has proved to have a high predictive value and is in wide use in the Navy. Recently it has been adapted for the selection of sound officers.

IV. RESEARCH IN NIGHT VISION

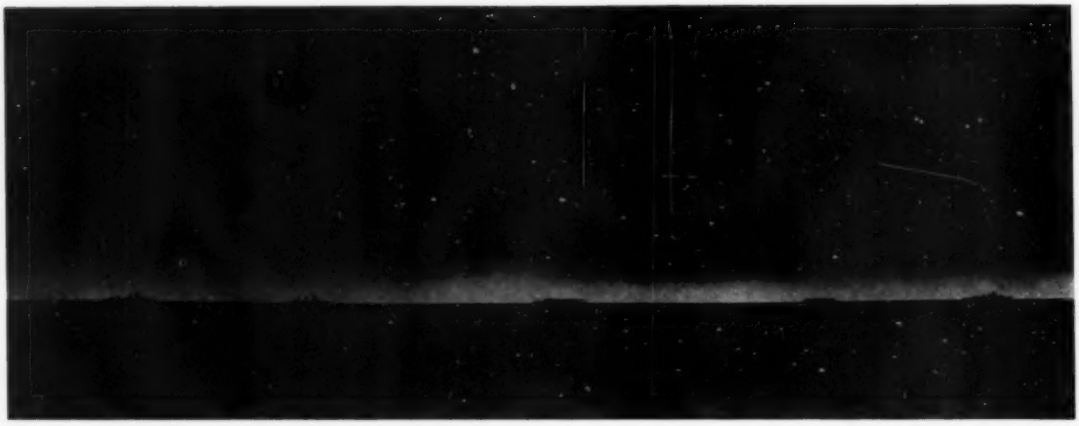
Night vision has been an important subject of research at the Medical Research Laboratory at the New London Submarine Base, for the importance of seeing and recognizing an enemy or friendly ship is obvious. The research program aims not only to improve the selection and training of personnel but also the improvement of techniques and physical equipment. To date more tests of night vision have been given at the New London Medical Research Laboratory than anywhere else in the Navy and at present a large proportion of submarine personnel is routinely tested. The Navy adaptometer, which the Medical Research Laboratory played a major role in selecting, is used here with efficient testing procedures also developed at that laboratory.

A program of night lookout training has been and is being developed at the laboratory. Both the procedures and the night lookout trainer itself are being improved on the basis of new knowledge. The men must learn to use their eyes somewhat differently to see a ship in the dark on a barely visible horizon and they must be able to recognize it instantly. Since night vision is a function of the rods at the outer portion of the retina, while the cones (upon which daytime vision depends) are less sensitive in the dark, the night watcher must learn to look at objects with the "tail" of his eye. It is difficult to learn not to look directly at the object one wishes to observe. To provide the necessary training, the Navy has devised a stage in a dark room, comparable in its lack of light to a photographic dark room, upon which men may observe conditions of lighting at sea corresponding to faint starlight, early dawn, swift lightning, sky-glow caused by poorly dimmed city lighting, and the dull red glow of a fire at sea. From benches placed before the stage the trainee watches the stage for the first faint ray of light and the silhouette of a submarine periscope or convoy. Tiny models accurate in every detail are used in this night lookout trainer. Only a section of the horizon is visible because in actual practice each watcher is assigned only a sector to watch. After sitting in total darkness or

FIG. 7. "Bends" susceptibility or bubble formation being studied by direct observation in monkey with Lucite cap.

Official U. S. Navy Photograph

FIG. 6. Cardio-vascular laboratory. Studies in Link trainers.



Official U. S. Navy Photograph

FIG. 8. Night lookout trainer to aid in quick recognition of objects on a barely visible horizon.

with eyes protected by goggles developed by the Navy, the training procedure begins. A very faint change takes place in the utter blackness. Some eyes do not see that there has been a change. Others become aware of a horizon. Some persons can even spot ships. They must remember to look slightly above or below the object or a little to its left or to its right, to see it. The impression is very vague but it may never be clearer on actual lookout duty. Some men are able in this light to tell from which direction the ship is approaching and whether it is a battleship, cruiser, destroyer, or other ship. Gradually the light on the horizon is increased while the room continues to be in total darkness and the observer begins to see many more ships. The night lookout trainer can also reproduce the conditions of visibility one finds during an electrical storm; the sudden flash momentarily revealing ships which is followed by seemingly greater darkness. The dull red glow of a fire at sea may be produced here as well as the blinding flash of gunfire, which does not illumine, unless the gunfire is behind a ship which it momentarily silhouettes against the flash.

Other types of trainers for specialized purposes have been originated or developed at the Medical Research Laboratory. A recognition trainer patterned after one first built at the Section Base, San Pedro, California, is being developed. Other research includes a study of the efficiency of various types of binoculars and dark adaptation goggles and the development of a training maze for amphibious and reconnaisance personnel.

The importance of color vision in observing ships, flags, and signals is recognized. Since there is no one whose color vision is absolutely "normal," and all have some degree of deviation from the average, it must be discovered what degree of deviation is acceptable to the submarine service in terms of efficiency and safety. This is the task of the color vision laboratory which investigates the degrees and kinds of deviation from normal color vision as well as their effect on the efficiency of submarine personnel.

Field tests are conducted under varying conditions of observation such as weather, distance, daylight, darkness, etc., on colored objects such as Navy color signals, flares, and rockets, recognition and running lights, channel markers, and indicator lights inside the submarines. In addition more than twenty laboratory tests are made: pseudo-isochromatic, lantern tests, various pigment-matching tests, time-response tests, and others. The results of the laboratory tests and field tests are correlated to give a better understanding of each individual's ability. Knowledge in the field of color vision is rapidly expanding partly because of our own research and partly because of the arrangement whereby data, methods, and apparatus are exchanged with British, Canadian, and Russian laboratories.

Most of the results of the Navy's New London Medical Research Laboratory are put to practical test at the Lookout Training School of the Medical Research Laboratory at the Submarine Base at New London. The school is teaching

future submarine personnel how to stand effective lookout watch—to scan an assigned sector most efficiently, to sight objects, and to report them accurately and sufficiently to their commanding officers in standard phraseology. The course includes intensive training in night vision, relative bearings, target and position angles, scanning and reporting, and taking proper care of instruments and of other equipment. In addition each man is given an intensive course in ship recognition to enable him to tell quickly the nationality and type of any ship of the belligerent nations.

After a week's work at their training courses the men are taken on a five-hour field trip aboard a vessel, during which they put into actual practice the training received at the school.

Another special training school conducted at the Medical Research Laboratory of the U. S. Submarine Base at New London is that for the training of pharmacist's mates for the submarine service.

Early in the war, it became apparent that the pharmacist's mates assigned to independent duty in submarines should be men of general well-rounded experience in all phases of the duties of hospital corpsmen, and have outstanding ability to analyze quickly a situation and apply appropriate remedial measures. A lack of an adequate supply of such well-qualified men developed, which prompted the laboratory to make a study of the background and experience of those assigned to independent duty, with a view to setting up certain qualifying standards. For a period of several months the pharmacist's mates who had volunteered for this duty and had been ordered to New London by the Bureau, were given a thorough written and oral examination in their specialty, as well as the usual battery of tests and interviews given other ratings in the submarine selection program. The data obtained in this way were compiled and classified. Some men were well qualified, some men were definitely disqualified, but there remained a middle group who were promising material, but lacked certain requisites. The establishment of the present school was the direct result of the study done on the results of the tests run on these men.

The purpose of the school is to give further training in those departments wherein lack of adequate experience is manifest in otherwise well-qualified candidates, as well as to give instruction in those subjects which are for the most part limited to submarine emergencies.

The pharmacist's mates satisfactorily completing this medical course are then sent to basic submarine school for six weeks and are then available for assignment to fleet submarines.

V. RESEARCH IN MEDICAL AND ENGINEERING PROBLEMS IN AERIAL WARFARE

The emergence of aviation as a major weapon is the spectacular feature of this war. In endeavoring to carry on aviation at higher and higher altitudes many problems requiring cooperation of engineers and physicians arise. Aviators must be furnished with devices and expedients which will maintain approximately atmospheric conditions of man's normal habitat. They must be so clad as to be protected from temperature and pressure changes and they must be furnished a supplementary respiratory apparatus designed to conserve the complex functioning of that salt-colloid medium called blood. Engines can carry planes into rarefied atmosphere and bombsights are accurate at great altitudes, but unless the aviator's altitude limits are extended at a rate equal to those of his machine, a nation cannot hope for air supremacy. Hence the outcome of the war, indeed, the future complexion of the world, hinges greatly on the success of medical research in connection with aviation.

The laboratories of the Naval Air Training Center at Pensacola, Florida and at Cedar Point,

FIG. 9. Extraction and purification of penicillin at 4°C.

Official U. S. Navy Photograph

FIG. 10. Sound laboratory showing recorders and synthetic airplane noise generator.

Maryland are conducting research on the practical aspects of aviation problems. These complement the more fundamental researches carried on at Bethesda, Maryland and elsewhere. Most of the time is spent in actually testing men and equipment at the aviation laboratories. The accompanying diagram indicates the chief administrative relationships obtaining at the U. S. Naval Air Station, Pensacola, Florida.

One of the most important problems in aviation is that of supplying the flyer with an adequate amount of oxygen. At any elevation above 10,000 feet an animal organism suffers from lack of oxygen. The greater the elevation the greater the amount of oxygen necessary. Individuals vary in their reaction to altitude. Consequently much research is being directed to selecting personnel resistant to hypoxia (anoxia), for which tests are made by subjecting the aviators to simulated high altitudes in steel chambers, and providing them with adequate equipment which will deliver the necessary additional oxygen in a safe and economical manner at the extremely low temperatures prevailing in the upper atmosphere; and by investigating correlated problems involving a consideration of carbon dioxide and carbon monoxide.

Supplying oxygen is not the whole solution of a problem of aviation at extremely high altitudes, for beyond 44,000 feet life can be maintained only by supplying another element of normal environment, namely, atmospheric pressure. The development of pressure-breathing apparatus, pressurized suits, and pressurized cabins requires the cooperation of the engineer, the pilot, and the physician.

Decompression

Decompression illness is another important problem which involves the testing of individual susceptibility at simulated very high altitudes and the testing of various protective measures. The illness known as "caisson disease" is similar to the "bends" experienced by the diver in rising from depths to the surface. In the latter as in the aeroembolism suffered by the aviator in rising from sea levels to high altitudes, the symptoms are caused principally by the liberation of gases from the tissues and fluids of the body because of low barometric pressures. While there do form visible bubbles which act mechanically to obstruct circulation, perhaps in vital organs, there is also an antecedent state characterized by an acute and chronic symptomatology. The nature of pre-embolic changes is obscure but something is being done toward preventing them by grounding of susceptible personnel, by elimination of nitrogen from the body by pre-oxygenation, and by study to determine factors within the body predisposing to occurrence of the disorder.

Motion sickness which affects certain flyers, particularly the crews of large aircraft and of gliders, is being studied. The possible causes commonly listed number at least twenty ranging

Official U. S. Navy Photograph

FIG. 11. Testing speech and listening intelligibility of pilots. Standard and improved Gosport systems.

from abnormalities of vision and hearing to suggestion.

Anti-*G* Measures

When a dive-bomber hurtling downward at a speed of four, five, or six hundred miles per hour reaches the low point of his descent and noses sharply upward, or when a steep bank is taken at high speed, both plane and man are subjected to a terrific strain. Measured in units of gravity, the centrifugal force may amount to six or seven *G*: that is, for several seconds the pilot weighs 1000 pounds or more. Under the pull, hernial protrusions break out, prolapse of the rectum occurs, veins rupture, and backs are wrenched. The blood, heavy as molten lead, gravitates toward the extremities, and for a matter of seconds the vasomotor system is quite unable to effect compensatory adjustments. Circulation is arrested, and there ensues syncope from acute cerebral anemia—what the aviator knows as "black-out."

Here is the one field in which medicine is ahead of engineering. With the aid of huge "human" centrifuges, there have been developed devices which fortify the pilot against degrees of *G* stress far beyond the structural strength of planes.

By means of automatically operated pumps and valves, serving a specially constructed suit enclosing the body and extremities, it is possible to create external supporting pressures, proportional to the *G* stress but graduated in degree from the lower extremities upward. A refinement consists of feeding oscillating pressure in such a fashion as to massage the limbs, thus maintaining circulation during the dive.

Low Temperatures

Besides protecting the pilot from the occasionally experienced effects of decompression and multiples of gravity, we must insulate him from extreme cold.

Great improvement in lightweight, flexible clothing for shielding the body from both still cold and wind has been brought about by studies relating to materials, yarns, and weaves, but the requirements created by rapid translation through a temperature range of 200°F can apparently be met only by tapping external sources of heat.

Official U. S. Navy Photograph

FIG. 12. Apparatus for preparing visual contrast tests to demonstrate retinal anoxia.

While it is possible to circulate within an impervious suit heated air drawn from the power assembly, a more practical equipment is the electrically heated suit. This, although it still has drawbacks, has been developed to the point that a pilot can fly in an open-cabin job when atmospheric temperatures approach 90°F below zero.

Visual Problems

There are two general types of visual problems: first, methods for testing the individual for purposes of selection, classification, and maintenance; second, control of instrument design and operating conditions to provide maximum visual efficiency.

Dark adaptation, the power to adapt quickly and completely to low visibility, is extremely important for night raiders, men going on night watch, and submarine lookouts. Since it does not vary significantly among normal individuals, the adaptometer is being developed more as a means for testing men and the effectiveness of methods devised to shorten the time required for an individual, on emerging from a lighted compartment, to gain full night vision.

Inasmuch as the light rays prevailing at night lie near the blue end of the spectrum, the color of illuminant used in the compartment is pure red, and the full sensitivity of the eye to blue is thus preserved as if by perfect darkness. On the same principle, red goggles may be worn, the individual

in that case being able to move about and read by ordinary illumination and yet on going out into the night enjoy the maximum possible vision in three minutes instead of thirty. These matters have ceased to be wholly subjects of research; they are accomplishments.

An extension of this same problem of night vision is to protect the adapted night observer from loss of adaptation by exposure to uncontrollable sources of light—illuminated instrument gauges and the dazzle of search lights, exploding shells, discharges of guns, tracer bullets, and illuminated instrument panels. For military reasons, I cannot go further into this matter.

The Pensacola U. S. Naval Air Station is also carrying on research on hearing devices and training in speech. Pilots must be taught, in many instances, to speak distinctly. Equipment for the transmission and reception of sound is being continually improved.

Pilot Fatigue

"Fatigue," like "shock," is a make-shift term for a condition the nature of which is obscure. We know that it must be basically psychogenic and that its onset and severity are influenced greatly by contributory factors such as lack of sleep, over-exertion, cold, heat, hypoxia, visual strain, noise, vibration, and emotional tensions. We know that the mechanisms involved in fatigue may find other expressions as in neurosis or gastric ulcer. We know further that nearly 75 percent of all flying accidents result from impairment of judgment or skill due to fatigue, and doubtless the same figures obtain in combat casualties. We have learned that barring accident or enemy agency, every pilot will break down when the stresses have been sufficiently severe and prolonged. But we remain so ignorant of its nature that our only remedy is to interrupt as far as possible exposure to strain by frequent periods of rest and recreation, a measure which serves only to postpone the inevitable hour. Meanwhile, we are studying this fatigue that we may find means of preventing or at least alleviating an extraordinary drain on our combat strength.

Much work is also being done in the selection of aviation personnel and their allocation to the various branches of the service according to their desire and suitability.

The range of problems studied by the various laboratories of the Research Division of the Bureau of Medicine and Surgery of the U. S. Navy encompasses the entire field of the human being under modern conditions of warfare. Many subjects of research are necessarily secret, but those mentioned here serve to demonstrate the dependence of military might and technological superiority on the continued functioning of the healthy human being, whose health, in turn, is dependent on medical science.

Research Activities of the Bureau of Naval Personnel

BY REAR ADMIRAL LOUIS E. DENFELD, U.S.N.
Assistant Chief, Bureau of Naval Personnel

REAR ADMIRAL
L. E. DENFELD

THE research activities of the Bureau of Naval Personnel are conducted to expedite the selection, training, placement, and ultimate utilization of officers and enlisted personnel in the work for which they are best suited. These activities include the construction and standardization of selection tests and procedures; the development of training programs, manuals, and courses; the preparation of curricula; and the establishment of measures of achievement.

It is an established fact that the design and construction of intricate machinery require highly technical training in natural sciences. It is equally true that, as machines become more complex, the problem of finding people to operate them intelligently becomes correspondingly complex. Moreover, the preparation and training of these people must be done in the shortest possible time. Consequently, the war requires not only skilled mechanical technicians, but equally adept personnel technicians.

Just as leisurely hit-or-miss research methods are impractical now, so trial-and-error personnel methods are inadequate and out of place. The goal of the Navy is to make exact and efficient assignments. This is expressed in the research work of the Bureau in its production of sensitive instruments capable of measuring human differences.

While the physicist investigates the nature of physical forces, then attempts to harness, control, and measure them, the personnel psychologist observes human behavior, and, on the basis of his observations, sets up quantitative measures of this behavior. The limitations and potential errors inherent in research methods are recognized in the final analysis of results.

Current research in personnel problems centers about the following areas:

(a) Exact and detailed descriptions of the work of skilled, well-trained personnel on specific jobs. Commonly called job analysis, this is referred to in the Navy as billet analysis.

(b) The development of measures of intelligence, knowledge, aptitudes, special skills, and psychological adjustment for the selection and classification of personnel.

(c) The preparation of training methods and curricula.

(d) The standardization of proficiency levels, so that the degree of achievement after training can be ascertained.

One of the major projects of the Bureau, and one which is fundamental to the development of the most effective selection and classification procedures, is an operational description of all Navy billets. Trained personnel psychologists visit shore stations and travel with the fleet, interviewing every type of personnel, observing them at work, and collecting descriptions of precisely what is done in hundreds of specialized jobs. These data are recorded on standard forms prepared for the purpose. With this information, the questions, "Selection for what?" and "Training for what?" can be concretely and specifically answered.

The actual selection program begins with the administration of the basic battery of tests. Included in the battery are general classification tests, and tests of reading and arithmetic, mechanical aptitude, mechanical knowledge, electrical knowledge, spelling, and clerical aptitude. These are given during the first ten days of recruit training. Norms, or national standards of performance, have been established so there is a common basis for interpreting the meaning of any score on any one of the tests.

On the basis of results on the general classification test battery and special tests, educational and professional achievements, physical qualifi-

cations, and leadership ability, recruits are either detailed to general duty or sent to school for special training, depending on the potentialities of each man.

In addition to this general testing program, there are qualification tests for officer candidates, including the Women's Reserve, and tests to select officers for highly technical billets. At the end of a standard training period, there are achievement tests to measure how well a skill has been learned.

The Navy is not interested in developing tests out of mere academic curiosity. Each test must prove its value as a potent means of selection. Considerable time and effort, therefore, are spent in discovering both the possibilities and limitations of a test. First, it is important to know whether the test measures what it is designed to measure, i.e., its validity. To accomplish this, the test is compared with a criterion which is assumed to measure the same trait. This criterion may be the performance of the task itself under normal working conditions, another test, or the combined judgment of experts. An equally vital step in research methodology is determining the reliability of a test, or how consistently it measures what it professes to measure. It is interesting to note here that psychological tests do not usually have as high a reliability as physical or mechanical tests, because human behavior cannot be controlled as well as physical behavior.

At present a number of research studies are in progress to determine which tests are most efficient in predicting success in the various naval training schools, and to establish the scores below which failure is probable. Scores on these tests are correlated with the recruits' grades at the school, and those tests correlating most closely with the grades are used to select personnel for assignments at the particular schools. This method of selection has been used experimentally for picking trainees in such schools as quartermaster, fire controlman, electrician's mate, radioman, machinist's mate, and gunner's mate. Prediction studies have also been made to choose officers for special courses.

Other research studies, in various stages of development, are in progress at several schools. For example, a radio code aptitude test has been designed to improve the selection of radio operators. This test consists of recognition of sound patterns, and measures essentially the ability of men to master sample letters of a code under uniform experimental conditions.

Because a study at one important training activity revealed a high proportion of failures among the students directly traceable to emotional or personality disturbances, a personal inventory was set up. This proved successful in picking out men who were later disqualified for some type of psychological imbalance. This test is now in use to screen out cases for psychiatric consideration. It will probably reduce the percentage of failures during training.

Another study is underway on the selection and training of naval gun crews. Several manuals and lesson plans for use in the instruction of naval personnel on the 0.50, 20-mm, 40-mm, and 5″ 38 guns have been prepared and adopted for use at anti-aircraft gunnery training stations. Procedures have also been developed for training interviewers who will have charge of the assignment of men to specific duties in the Navy. Recordings of instruction in gunnery are being made for future use in the standardization of gunnery terminology and for the improvement of instruction methods. Research is also under way to develop criteria of accuracy in practice anti-aircraft firing. A number of apparatus tests and pencil and paper tests are under construction for use in the prediction of accuracy of fire. A pilot study of the physical and mental characteristics of men assigned to gunnery training at one station has been completed. Projects have been planned to improve the selection of telephone talkers and oscilloscope operators.

Standard curricula have been instituted in a great many training schools, so that a graduate of one school will have approximately the same background as a graduate of a similar school.

As part of this effort to achieve uniformity, instructor training courses have been set up, emphasizing the importance of rigid adherence to the course as outlined in the manual, in itself a description of the material to be covered.

Thus the Bureau of Naval Personnel has worked toward fulfilling its role in this emergency through the use of scientific methods and scientific tools.

Here and There

Staff Changes

Professor Duane Roller, Editor of the *American Journal of Physics*, has resigned from Hunter College, New York City, to head the department of physics at Wabash College, Crawfordsville, Indiana. He assumed his new duties on March 1.

Professor Joseph D. Elder has also joined the physics staff at Wabash College, having resigned from Lynchburg College. In addition, he will occupy the newly created position of Assistant Editor of the *American Journal of Physics*. Professors Roller and Elder will continue work for the National Defense Research Committee in which they were jointly engaged in Washington.

It was announced recently that William A. Foote has been appointed Sales Coordinator of Littelfuse Incorporated, El Monte, California and Chicago, Illinois. Mr. Foote was, at one time, President and General Sales Manager of the Wingfoote Petroleum Company, affiliated with the Standard Oil Company of New York as Marketing Counsel, and National Director of Sales of the Deoxolin Chemical Corporation.

A recent promotion was received by Donald H. Jacobs from the position as associate physicist at the National Bureau of Standards to senior physicist at the U. S. Naval Observatory, Washington, D. C.

It has been announced in *Science* that Professor Ora S. Duffendack, since 1922 a member of the faculty of the University of Michigan, has resigned to accept a position in private industry with the North American Philips Company of New York City. He will organize and direct a new research staff and laboratory for which he will be given a free hand in selecting both research fields and staff members. He will sit in on the board of directors of the company. For the past two years he has been chief of a research section of the National Defense Research Committee in the Randall Physics Laboratory of the university. He expects to continue to supervise this work.

Honors and Awards

Dr. Irving Langmuir, Associate Research Director of the General Electric Company of Schenectady, New York, has received the Faraday Medal from the British Institute of Electrical Engineers for his outstanding contributions to electrical science. Dr. Langmuir's work has ranged over a wide field, from hard vacuum tubes to atomic hydrogen welding. He has been engaged in the development of secret military devices.

At a recent luncheon given by the Jewish Education Committee of the League of Fraternal and Benevolent Organizations, presentation of their annual award was made to Professor Arthur H. Compton by Edgar J. Nathan, Jr.

Dr. Ferry C. Houghten, now a Lieutenant Commander, United States Naval Reserve, has been awarded the F. Paul Anderson Medal of the American Society of Heating and Ventilating Engineers. The award is made to Dr. Houghten, "for outstanding research over a long period of years in the fields of heating, ventilating and air conditioning, resulting in distinct benefits to the public and the nation; for the advancement of the knowledge of the physiological reactions of persons to their environments and for the careful presentation of technical data readily adaptable to general use in engineering."

News Note

The New School for Social Research (École Libre des Hautes Études) at 66 Fifth Avenue, New York City, has announced in its bulletin, the course, "La propagation d'ondes dans les reseaux cristallins" given by Léon Brillouin.

Professor C. J. Fordyce, M.A., Clerk of Senate, the University of Glasgow, has asked for assistance in order to complete the record of business connections and addresses of former graduate and non-graduate students of the University. It will be much appreciated if all former students will communicate with Professor Fordyce giving him the above-mentioned information.

Calendar of Meetings

April	
2–5	American Ceramic Society, Pittsburgh, Pennsylvania
3–7	American Chemical Society, Cleveland, Ohio
5–7	Society of Automotive Engineers, New York, New York
15	American Association of Physics Teachers, Indiana Chapter, Indianapolis, Indiana
15	American Association of Physics Teachers, Western Pennsylvania Chapter, Pittsburgh, Pennsylvania
15	American Physical Society, New England Section, Simmons College, Boston, Massachusetts
19–21	American Society of Civil Engineers, St. Louis, Missouri
20–21	American Institute of Mining and Metallurgical Engineers, Pittsburgh, Pennsylvania
20–22	American Philosophical Society, Hall of the Society, Independence Square, Philadelphia, Pennsylvania
24–26	National Academy of Sciences, Washington, D. C.
25–27	Society of Motion Picture Engineers, New York, New York
27–29	American Physical Society, Mellon Institute, Pittsburgh, Pennsylvania
28–29	American Mathematical Society, Chicago, Illinois
28–29	American Mathematical Society, New York, New York
29	American Mathematical Society, Berkeley, California

Erratum: Resolution of Boundary Value Problems by Means of the Finite Fourier Transformation: General Vibration of a String

[J. App. Phys. **14**, 609 (1943)]

HERBERT K. BROWN
Rensselaer Polytechnic Institute, Troy, New York

(a) Page 611, cosine transforms:

$$\text{Instead of } \mathfrak{C}\left\{-\frac{\pi}{6}+\frac{x^2}{2\pi}\right\}=\frac{(-1)^{n+1}}{n^2},$$

$$\text{read} \qquad \mathfrak{C}\left\{-\frac{\pi}{6}+\frac{x^2}{2\pi}\right\}=\frac{(-1)^{n}}{n^2}.$$

(b) Page 614, top of page,

instead of

$$W(x,t,\tau)=-\int_{-\pi}^{\pi}[V_1(x-\xi,t)\,V_2(\xi,\tau)-V_1(x-\xi,\tau)\,V_2(\xi,t)]d\xi,$$

read

$$W(x,t,\tau)=-\frac{1}{2}\int_{-\pi}^{\pi}[V_1(x-\xi,t)\,V_2(\xi,\tau)-V_1(x-\xi,\tau)\,V_2(\xi,t)]d\xi.$$

This correction is apparent only when $W(x, t, \tau)$ is stated explicitly in the form of a definition, such as

(c) page 615, $\quad W(x,t,\tau)=\cdots$

(d) page 618, $\quad W(x,t,\tau)=\cdots$.

Erratum: Transmission-Line Theory and Its Application

[J. App. Phys. **14**, 577 (1943)]

RONOLD KING
Cruft Laboratory and the Research Laboratory of Physics, Harvard University, Cambridge, Massachusetts

EQUATION (8b) change subscript 0 to s in second θ_0 in numerator.

Equation (19a) add r at extreme left to give $r_{1\,in}$.

Figure 6 change $\Phi_s'=3\pi/4$ to $\Phi_s'=5\pi/4$ at lower right.

Equation (73) change $1+a^2/b^2$ to $(1+a^2/b^2)^{\frac{1}{2}}$.

Equation (91b) change the 2 in the denominator to 4.

Equation (132) change $(\cosh^{-1} b/2a)$ to $(\cosh^{-1} b/2a)^2$.

Page 584, Table I, add "squared" after "radius of circle."

Page 592, above Eq. (81), change "and" to "end."

WHICH WAY HOME?

FLYING THROUGH FOG and storm, navigators must depend upon the compass. They must know, beyond all doubt, that their compass readings are accurate.

Measuring compass dependability is the function of the Waugh Magnetometer. With it, all magnetic fields, residual and induced, in the aircraft and in the cargo can be plotted, to provide the navigator with an accurate deviation chart.

Rule-of-thumb magnetic inspection will no longer suffice. The utmost accuracy, as assured with the Waugh Magnetometer, now is mandatory. Booklets 90 and 91 describe the materials inspection and airframe analysis types of magnetometers.

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Recent Applications of Physics

Prepared by CLARK GOODMAN, Associate Editor

Material to be included in this section should be submitted to Dr. Clark Goodman, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

Radioactive Tracer in Tubing Almost as legendary in physics as the R. W. Wood stories are the tales of locating lost radium by the use of portable Geiger-Mueller counters. This principle has recently been applied to the exploration of operating structures such as catalytic cracking equipment and oil pipe lines. A tube of radium or radioactive mineral is lowered in a heat-exchange tube at the same rate as a G-M counter traverses an adjoining tube. Voids or localized fused masses of catalyst are indicated by variations in the intensity of the observed gamma-rays. Similarly, a partial obstruction in a surface pipe line (or one of shallow burial) can be located by introducing a plug containing radioactive material and following its progress through the line with a G-M counter carried along the outside of the line. Movement of the plug ceases when it reaches the obstruction. Details of the method are given in U. S. Patent 2,315,819 granted to C. H. Schlesman, assignor to Socony-Vacuum Oil Company.

Plastic Contact Lenses Glass contact lenses have been used to a limited extent during the last half-century largely to correct visual defects of the cornea and to prevent infection of the eye by a diseased lid. The use of plastics for this purpose is a recent development that offers a number of advantages. Because every eye has its own individual shape, contact lenses must be custom made. In order to obtain the necessary accurate fit, a thermo-plastic cast of each eye is made.

The preparation of the cast requires only a few minutes during which the eye is anesthetized. A plaster positive of this cast serves as a mold for the finished plastic lenses of the type shown in the photograph. The contact lens must clear the cornea and limbus, yet rest on the scleral portion of the eye sufficiently snugly to adhere, while being loose enough not to exert undue pressure on the blood vessels and nerves. The space between the plastic lens and the cornea is filled with a liquid which not only eliminates refractive errors caused by irregularity of the cornea but acts as the necessary hydraulic shock absorber and lubricant. The composition of this solution is adjusted to match as closely as possible the fluid in the cells of the eye, which also varies with the individual. The accuracy of this match is equally as important as the fit in determining the length of time the lenses can be worn with comfort. The usual tolerance is from four to eight hours.

In contrast with glass, plastic lenses are unbreakable, which offers more of a psychological than an actual advantage. The lighter weight—40 percent that of glass—and slightly better light transmission of the plastic are additional advantages. At present such lenses are particularly of value to sportsmen, actors and actresses, and other persons engaged in work where ordinary spectacles are impractical. With continued improvements it is likely that contact lenses will find more widespread general acceptance. Further information can be obtained from the Obrig Laboratories of New York City.

Zenith Camera The Eastman Kodak Company is now producing a three-unit zenith camera which allows aerial photographs made by the Army and Navy to be located in terms of longitude and latitude with an uncertainty of less than ½ second (50 feet). A visual optical system allows the true zenith to be established after which a group of cameras simultaneously photographs the portion of the night sky immediately surrounding the zenith, illuminated land objects, and a group of three navigation watches set on Greenwich time. By coordinating these observations with reconnaissance photographs made during daylight, accurately located aerial maps can be prepared. After the war this technique should aid in improving the accuracy of geographical survey maps.

Supersonic Tire Tester Hidden separations within tires are readily detected and located by a supersonic tire tester developed in the Research Laboratories of the Goodyear Tire and Rubber Company. The tire to be inspected is hung on two rollers in such a way that the bottom portion passes through a shallow tank of water in which ultrasonic waves are generated by a magnetostrictive oscillator. The vibrations are transmitted through the tire to a microphone immersed in a small quantity of water within the tire. The detection of a separation depends upon the reflection of the highly directional ultrasonic waves at a rubber-air interface. The amount of opening is not involved in its detection; a very thin air film or unusual amount of porosity is sufficient. A check on the sensitivity and performance of the device is readily made by attaching to the tire surface by adhesive tape a "sandwich" composed of two thin sheets of rubber cemented together around the edges. Only a few minutes are required, and the method is proving of particular value in eliminating waste and inefficiency in the retreading of defective tires, especially large truck and bus tires.

KEEPING UP WITH *Electricity*

1000 REVOLUTIONS PER SECOND! That's the speed of newest Westinghouse motor, producing a tool surface speed of 7,000 feet per minute. This 4 horsepower induction motor has a rotor only 2 inches long, diameter 1¾ inches. Westinghouse engineers are now developing a motor to go *twice as fast*.

B'R'R'R'R'R . . . A polar bear would be right at home at 20° below zero in the Westinghouse "igloo" at East Pittsburgh. This cold chamber is 1500 times as large as the average electric home refrigerator. Here, Westinghouse engineers test ice-coated circuit breakers and other electrical switching equipment, to guarantee operation under worst winter conditions.

HIGH LIFE IS HARD on carbon generator brushes in high-flying bombers. They used to wear down to the pigtails in an hour or two, at 30,000 feet. Now Westinghouse engineers have developed a chemical treatment that keeps the brush face lubricated at substratosphere heights. Result: *fifty-fold* increase in brush life . . . enough for a dozen raids over Berlin.

EVER SEE A MILLIONTH of an inch? Probably you never will — but the Electrigage can *feel* as little as twelve millionths. Developed by Westinghouse and Sheffield Corporation, it can measure with a precision equal to finding an error of three-quarters of an inch in a mile. Infinitesimal movement of gauging stylus induces a tiny current, which is amplified 10,000 times.

AIR IS HEAVY STUFF when you start pushing it around at 400 miles an hour. That's why U. S. Army needed a 40,000 horsepower electric motor to create a man-made hurricane, for testing airplanes in Wright Field wind tunnel. It is the world's largest wound-rotor induction motor, designed and built by Westinghouse engineers.

Chemical analyses — *right now!*

Above is the laboratory model of the Westinghouse mass spectrometer, which sorts out dissimilar molecules according to their mass, and does it almost as fast as you can snap your fingers.

The mass spectrometer provides a new way to get the quick, accurate analyses that are needed to maintain precise process control. Take the synthetic rubber industry, for example. Formerly, five men took as long as three days to complete necessary chemical tests in the processing of artificial rubber—which meant that the results were often too late to be useful.

The new electronic "chemist," the Westinghouse mass spectrometer, now makes these tests in about 15 minutes.

For leadership in the electrical solution of industry's problems, look to Westinghouse. *Westinghouse Electric & Manufacturing Company, Pittsburgh 30, Pennsylvania.*

Tune in John Charles Thomas, NBC, Sundays, 2:30 p.m., E.W.T.

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Continuous Flow Refractometer In order to maintain the purity of butadiene used in the manufacture of synthetic rubber, the Shell Development Company has developed a method of continuously measuring the refractive index

of the liquid product. Since butadiene boils at 19°C under normal conditions, the refractometer operates somewhat above atmospheric pressure. The index is measured by means of a prism mounted in a transparent tube through which the liquid flows at a constant temperature. Both pressure and temperature can be adjusted to meet the requirements of various liquids. The instruments, one of which is shown in the photograph, are available from the Precision Scientific Company of Chicago.

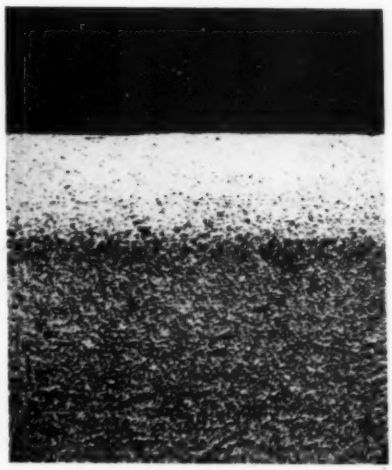
Dehydration of Food The Federal Telephone and Radio Corporation has developed a process of dehydrating food by means of radio-frequency energy that makes possible, for the first time, removal of 99 percent of the moisture from a compressed vegetable block. Conventional methods of dehydration, using heat and forced air, often cannot remove more than 95 percent of the moisture content without developing a cooked crust. This permanent change prevents reconstitution of the vegetable by soaking in water. Unless the moisture content is reduced to less than one percent of the original amount, many root or semiperishable vegetables, including beets, carrots, cabbages, onions, and potatoes, will keep only a few weeks in humid atmospheres and cannot be packed satisfactorily inasmuch as mold forms, which renders the food inedible.

The electronic dehydration method makes it possible to pack dehydrated vegetables in sealed containers and transport them to any part of the world without danger of decomposition. The reconstituted vegetables may be cooked and served the same as fresh vegetables. The original color, consistency, taste, and aroma are retained. The vitamin content of electronically dehydrated vegetables is especially high because of the shorter processing time. In his report covering this original work, V. W. Sherman of the Federal Telephone and Radio Corporation states that laboratory tests indicate that the removal of one pound of water requires less than one kilowatt-hour of energy, making the method economically reasonable.

Not only is this development of value in supplying the present needs of our armed forces, but it will undoubtedly be of considerable importance in helping solve the enormous problem of feeding the postwar world.

Case Hardening Induction heat-treating, melting, and baking-out of metals have been in use for many years. The frequencies employed are generally below 0.5 megacycle. With modern short wave broadcasting equipment, it is now possible to extend the range to 5–15 megacycles with several hundred kilowatts of power. V. W. Sherman, of the Federal Telephone and Radio Corporation, recently reported the advantages of these higher frequencies in the thin case hardening of steels.

Because of the skin effect, the thickness of layer heated varies inversely as the square root of the frequency. Uniformly hardened cases, 5 to 30 mils thick and controllable within ±1 mil, have been produced using 5-megacycle energy. A typical example is shown in the accompanying sectional microphotograph. The method produces no distortion or scaling. Hence, parts can be case hardened after having been finished to final dimensions. The transition in characteristics from case to core takes place smoothly



and in a distance short compared to the case thickness. Because the surface layer is heated for such a short time, less than one second, no measurable tempering action has been observed in the adjacent metal core. Following the brief heating period, rapid chilling of the surface takes place by conduction to the cold core. Thus an additional advantage of this physical technique is that the metal parts may be made self-quenching.